2022 Brandywine Watershed Report

DELAWARE DEPARTMENT OF NATURAL RESOURCES AND ENVIRONMENTAL CONTROL

Erin E. Dorset
Kenneth E. Smith
Alison B. Rogerson
Olivia McDonald

Delaware Department of Natural Resources and Environmental Control
Division of Watershed Stewardship
285 Beiser Boulevard, Suite 102
Dover, DE 19904

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Executive Summary

The Delaware Department of Natural Resources and Environmental Control's (DNREC) Wetland Monitoring and Assessment Program (WMAP) documented wetland acreage trends and determined the ambient condition of non-tidal wetlands in the Brandywine watershed in 2019. The goals of this project were to summarize acreage gains, losses, and changes across the Brandywine watershed based on the most current state wetland maps; assess the condition of non-tidal wetlands throughout the watershed; identify prevalent wetland stressors; assess the value that non-tidal wetlands provide to the local landscape; and make watershed-specific management recommendations to different audiences, including scientists and land managers, decision makers, and landowners.

The Brandywine watershed is in the northernmost part of Delaware in the Piedmont region, and it extends farther north into Pennsylvania. The Delaware portion of the watershed is located within New Castle County, where it encompasses 72,969 acres (114 square miles) of land. It is composed of eight sub-watersheds at the hydrologic unit code (HUC) 12 level, including Upper White Clay Creek, Lower White Clay Creek, Red Clay Creek, Middle Brandywine Creek, Lower Brandywine Creek, Matson Run-Shellpot Creek, Oldmans Creek-Delaware River, and Stoney Creek, which were combined for this project and report. For simplicity, this watershed complex is referred to as 'Brandywine'. Approximately 3% of the land area of the watershed was covered by wetlands according to Delaware's 2017 land use and land cover (LULC) dataset. The main types of vegetated wetland types in this watershed, which were the targets of wetland assessments, were flat, riverine, depression, and seep wetlands. Of these wetlands, 13% were non-tidal flats, 38% were non-tidal riverine wetlands, 18% were non-tidal depressions, and 31% were non-tidal seeps.

WMAP estimated historic (prior to 1992) and more recent (1992 to 2017) wetland losses in the Brandywine watershed based on historic hydric soil maps as well as 2007 and 2017 statewide wetland mapping resources. Analysis indicated that by 1992, approximately 936 acres of the watershed's historic wetlands had been destroyed for development. Between 1992 and 2017, the watershed lost another 42 acres of wetlands, meaning that by 2017, an estimated 26% of historic wetlands in the watershed had been destroyed. The Brandywine watershed also gained approximately 162 acres between 1992 and 2017, resulting in a net gain of 121 acres between those years. Most of the recent wetland acreage loss was due to development, construction of roads or parking lots, or creation of golf courses. Most of the recent gained acreage was attributed to the creation or expansion of non-vegetated ponds. Other wetlands changed wetland type from 1992 to 2017. The most common types of changes were from non-vegetated to vegetated wetlands, from vegetated to non-vegetated wetlands, or clearing of wetlands that resulted in forest or scrub shrub habitat reverting back to emergent habitat.

To assess wetland condition and identify stressors affecting wetland health, rapid assessments were conducted at wetland sites throughout the Brandywine watershed during the summer of 2019. Wetland assessment sites were located on public and private property and were randomly selected utilizing a probabilistic sampling design with the assistance of the Environmental Protection Agency's (EPA) Ecological Monitoring and Assessment Program (EMAP). WMAP performed non-tidal wetland assessments in 14 flat wetlands, 24 riverine wetlands, 11 depression wetlands, and 19 seep wetlands using the Delaware Rapid Assessment Procedure (DERAP) Version 6.0. No tidal wetlands were assessed because there were very few tidal wetlands in the watershed.

Flat wetlands (n=14) had a mean condition score of 77.6 ± 13.1 (median=81.0) out of a maximum possible score of 95.0, ranging from 50.0 to 92.0. Riverine wetlands (n=24) had a mean condition score of 68.4 ± 15.9 (median=68.0) out of a maximum possible score of 91.0, ranging widely from 26.0 to 85.0. Depression wetlands (n=11) received a mean score of 62.7 ± 8.6 (median=65.0) out of a maximum possible score of 82.0, ranging from 48.0 to 78.0. Seep wetlands (n=19) received a mean score of 72.9 ± 10.7 (median=70.0) out of a maximum possible score of 91.0, ranging from 51.0 to 86.0. Compared with 11 other watersheds previously assessed in Delaware, the Brandywine watershed was most like the Mispillion watershed. Overall, the greatest proportion of wetlands in the Brandywine watershed were moderately stressed (77%), while 13% were minimally stressed and 10% were severely stressed. Invasive species were the most prevalent stressors within wetlands, while buffer disturbances, such as development or roads, were the most widespread types of stressors around wetlands.

Wetland value was also evaluated in non-tidal wetlands because wetland value to the local area may be independent of wetland condition. Value-added assessments were conducted at non-tidal sites using Version 1.1 of the Value-Added Protocol, in conjunction with DERAP v.6.0. Flat wetlands were found to provide limited (50%) or moderate (50%) value to the local area, offering the most value in terms of habitat structure and complexity and habitat availability. Similarly, most riverine wetlands were rated as providing limited (46%) or moderate (42%) value and were considered most valuable for their habitat structure and complexity and for their flood storage and water quality capacity. The highest proportion of depressions were rated as providing moderate value to the local landscape (64%), mostly because of habitat availability and habitat structure and complexity. Of all wetland types assessed, seeps provided the most value to the local area, as 90% were considered to supply rich value. This was largely because all seeps were considered ecologically significant as Category One wetlands. Additionally, seeps were considered fairly valuable in terms of habitat complexity and availability as well as flood storage and water quality capabilities.

Based on analysis and synthesis of all data collected for this report, WMAP made several management recommendations to improve overall wetland condition and acreage by targeting specific issues in different wetland types. These recommendations were tailored to different audiences, including environmental scientists and land managers, decision makers, and landowners. WMAP recommended that environmental scientists, researchers, and land managers work to maintain adequate wetland buffers, perform wetland monitoring, conservation, and restoration activities, control the extent and spread of non-native invasive plant species, continue to increase citizen education and involvement through effective outreach, improve coordination of watershed-based efforts, and continue to regularly update state wetland maps. WMAP also recommended that decision makers improve the protection of non-tidal wetlands, develop incentives and legislation for maintaining non-tidal wetland buffers, and secure funding for wetland preservation. Finally, WMAP suggested that landowners protect and maintain vegetated buffers around wetlands on their property, protect or enhance wetlands on their property, and engage in best management practices in urban and suburban settings.

Introduction

Wetlands are unique, beautiful ecosystems that are intrinsically valuable and provide many important ecosystem services to communities. Wetlands can remove and retain disturbed sediments, pollutants, and nutrient runoff from non-point sources (e.g., agriculture, land clearing, and construction) from the water column before they enter our waterways, thereby improving the quality of drinking and swimming water. By retaining sediments, wetlands also help to control erosion. Wetlands can minimize flooding by collecting and slowly releasing stormwater that spills over channel banks, protecting infrastructure and property. They also sequester carbon, meaning that they help remove excess carbon dioxide from the atmosphere and store it in their plant biomass and soils to potentially reduce the effects of climate change. Additionally, wetlands are biologically rich habitats and are home to many unique plant and animal species, some of which are threatened or endangered. They are critical resources for migrating shorebirds and wintering waterfowl and serve as nurseries for most commercial fish and shellfish species in Delaware. Wetlands are also valuable sources of recreation (e.g., hunting, fishing, kayaking, and birding) and livelihood (e.g., fishing, crabbing, and fur-bearer trapping).

The ecosystem services that wetlands provide supply significant contributions to local economies in Delaware that together total more than $1 billion annually. For example, flood control benefits provided by Delaware wetlands are valued at $66 million annually, and wildlife activities conducted in these areas such as birding, fishing, and hunting generate approximately $386 million annually. Additionally, Delaware's wetlands provide an estimated $474 million annually in water quality benefits (Kauffman 2018).

Wetland acreage, condition, and diversity are all crucial to the ability of wetlands to provide these beneficial services. If wetland acreage decreases, then there are fewer wetlands to perform vital ecosystem services to people and wildlife. Wetlands provide the greatest number of services when they are in good condition. Wetlands that have been impacted by removal of buffer habitat, altered hydrologically such as by ditching, or have been severed by a road, for example, will function at a lower capacity. Engineered solutions that are designed to replace some wetland ecosystem services, such as water treatment facilities, can be very costly to construct and maintain. Additionally, if wetland acreage decreases, it becomes more difficult for wildlife to disperse and migrate among wetland habitats, as distances between wetlands may grow larger. Such reduced dispersal and migration can reduce genetic diversity and population sizes of wildlife species (Finlayson et al. 2017). Different wetland types typically perform certain functions better than others based on factors such as position in the landscape, vegetation type, and hydrological characteristics (Tiner 2003); therefore, a variety of wetland types ensure that all services that wetlands can offer are provided.

Wetlands have a rich history across the region and their aesthetics have become a symbol of the Delaware coast. However, many wetlands that remain are degraded by the impacts of many direct and indirect stressors and are therefore functioning below their potential. Mosquito ditches, adjacent agriculture and development, filling, and invasive species are all examples of common stressors that Delaware wetlands experience that can negatively affect their hydrology, biological community, and ability to perform beneficial functions. Many anthropogenic wetlands, such as stormwater or agricultural ponds, cannot make up for the degradation of natural wetland function. This is because most created wetlands are non-vegetated and do not resemble natural wetlands, and they perform many functions at lower levels than natural wetlands (Woodcock et al. 2010, Tiner et al. 2011, Rooney et al. 2015).

While a portion of wetlands have been degraded, many others have been lost completely; approximately half of all historic wetlands in Delaware have been lost since human settlement in the early 1700s. This decline in wetland acreage has continued in recent years; between 1992 and 2007, there was a substantial net loss of 3,126 acres of vegetated wetlands across the state. Acreage losses have been particularly alarming for forested freshwater wetlands, which experienced the greatest losses of all wetland types between 1992 and 2007 (Tiner et al. 2011). These non-tidal wetland losses have largely occurred because of direct human impacts, many of which are likely the result of the lack of regulatory protection and enforcement. The state of Delaware regulates activities in tidal wetlands, but only in non-tidal wetlands that are 400 contiguous acres or more in size. Most non-tidal wetlands in Delaware are smaller than 400 acres. Federal regulations do exist for non-tidal wetlands, but not for small wetlands <0.1 acres in size, of which many exist. A lack of stringent enforcement presence on the ground leaves room for unpermitted losses. Moreover, very recent changes to the definitions of the Waters of the U. S. (WOTUS) have further lessened federal regulations for small or geographically isolated freshwater wetlands, leaving them vulnerable to conversion or destruction.

Tidal wetlands in Delaware also face many different challenges. Although regulated by the state, most of the recent tidal wetland losses have been caused by subsidence and submergence, highlighting the impacts of sea level rise from climate change. Acreage losses of tidal and non-tidal wetlands have led to the reduction of many beneficial functions, such as carbon sequestration, sediment retention, wildlife habitat, nutrient transformation, and shoreline stabilization (Tiner et al. 2011).

The state of Delaware is dedicated to preserving and improving wetlands through protection, restoration, education, and effective planning to ensure that they will continue to provide important services to the citizens of Delaware (DNREC 2021). Thus, the Delaware Department of Natural Resources and Environmental Control's (DNREC) Wetland Monitoring and Assessment Program (WMAP) examines changes in wetland acreage over time and monitors wetland condition and functional capacity to guide management and protection efforts.

Delaware's Approach

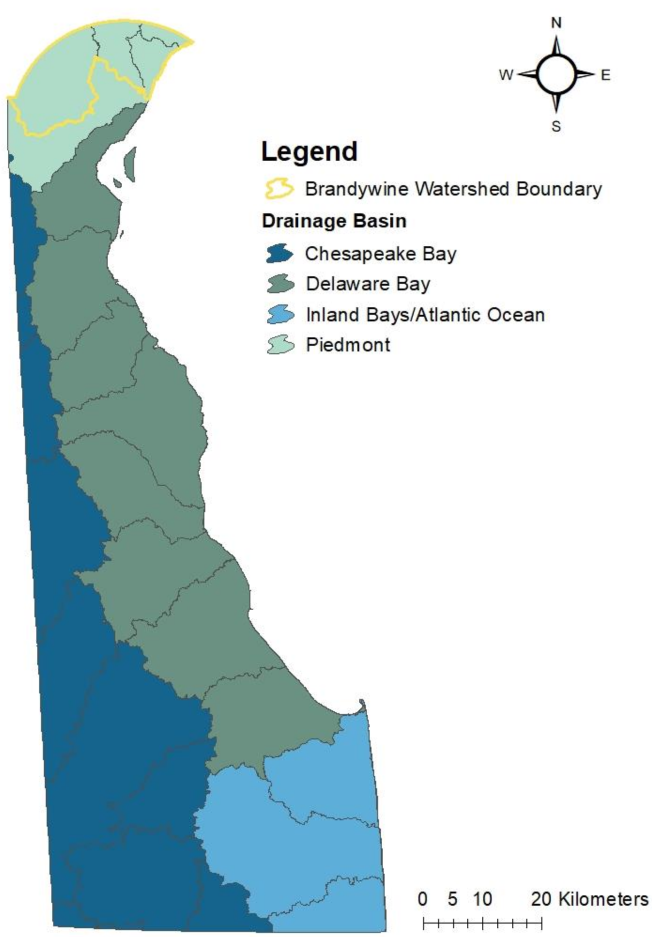
Since 1999, DNREC's WMAP has been developing scientifically robust methods to monitor and evaluate wetlands in Delaware on a watershed basis using a four-tiered approach that has been approved by the U.S. Environmental Protection Agency (EPA). WMAP evaluates wetland health (i.e., condition) by documenting the presence and severity of specific stressors that are degrading wetlands and preventing them from functioning at their full potential. Wetland assessments are conducted on four tiers, ranging from landscape-level to site-specific studies (Figure 1). The landscape level assessment (Tier One) is the broadest and least detailed and is performed on desktop computers using state wetland maps, while the rapid assessment (Tier Two), comprehensive assessment (Tier Three), and intensive assessment (Tier Four) are progressively more detailed and require active field monitoring. Of Tiers Two to Four, rapid assessments require less detailed data collection

Figure 1. The four-tiered approach that is used to evaluate wetland condition across the Mid-Atlantic region, including Delaware.

and shorter field days, while intensive assessments require the most intense field work, data collection, and analysis.

State wetland maps that are created for Delaware for desktop analyses include the two most common types of wetland classification: the Cowardin system (FGDC 2013), which is the main classification used by the U.S. Fish and Wildlife Service's (USFWS) National Wetlands Inventory (NWI; USFWS 2021), and the hydrogeomorphic (HGM) system, which describes landscape position, landform type, waterbody type, and water flow path (LLWW; USFWS 2014). WMAP considers both classification systems when performing desktop and field assessments. The Cowardin system is used for random selection of assessment points, splitting wetlands into estuarine, tidal palustrine, and non-tidal palustrine wetland types (see "Field Site Selection" in Methods section below). The HGM/LLWW system is then used in the field to differentiate among the most common non-tidal palustrine wetland types in Delaware based on hydrogeomorphic characteristics, which are flat, riverine, and depression wetlands.

Once these assessments are complete, data are extrapolated to generate overall watershed condition reports that discuss trends in wetland acreage, identify common stressors by wetland type, summarize overall health of wetland types, and provide management recommendations based on these results. Information and recommendations provided by these reports can be used by watershed organizations, state planning and regulatory agencies, and other stakeholders to prioritize and improve wetland protection and restoration efforts. For example, protection efforts, such as through acquisition or easement, can be directed toward wetland types in good condition, and restoration efforts can target degraded wetland types to increase their functions and services. In this report, WMAP discusses wetland acreage trends and wetland condition in the Brandywine watershed in northern Delaware, which are based on landscape (Tier One) and rapid (Tier Two) assessment data.



Map 1. Location of the Brandywine watershed and the major drainage basins in Delaware. Watersheds at the HUC10 scale are outlined in dark gray.

Watershed Overview

The Brandywine watershed is the northernmost watershed in Delaware and is part of the Piedmont region (Map 1). The Delaware portion of the Brandywine watershed that was assessed for this report is a combination of multiple watersheds at the Hydrologic Unit Code (HUC) 10 scale, including White Clay Creek, Brandywine Creek, Shellpot Creek, and Raccoon Creek. This watershed ultimately drains into the Delaware River.

The Delaware portion of this watershed encompasses 72,969 acres (114 square miles) of land in New Castle County and is composed of eight sub-watersheds at the HUC12 level: Upper White Clay Creek, Lower White Clay Creek, Red Clay Creek, Middle Brandywine Creek, Lower Brandywine Creek, Matson Run-Shellpot Creek, Oldmans Creek-Delaware River, and Stoney Creek (not shown on map). The entire Brandywine watershed continues north into Pennsylvania; however, this report only covers the Delaware portions of the watershed. The Christina River watershed borders the Brandywine watershed to the south.

Much of this watershed is developed, partly because the northern parts of Newark and Wilmington are included. Hockessin, North Star, Pike Creek, Greenville, Edgemoor, and Claymont are all also part of the watershed. Interspersed throughout those main developed areas are other small residential communities and urban areas as well as local and state parks.

Hydrogeomorphology

Prior to the last ice age, most of present-day Delaware was covered by the ocean. However, as polar ice caps expanded, the sea level decreased, exposing more land. Massive amounts of sediment from the ancient Appalachians were carried down the large Delaware and Susquehanna Rivers and settled onto the coastal plains of Delmarva. Repeated continental glacier advances and retreats and subsequent melting of polar ice caps helped to shape the relative sea level and dictate stream formations that comprise current watersheds (DNREC 2001).

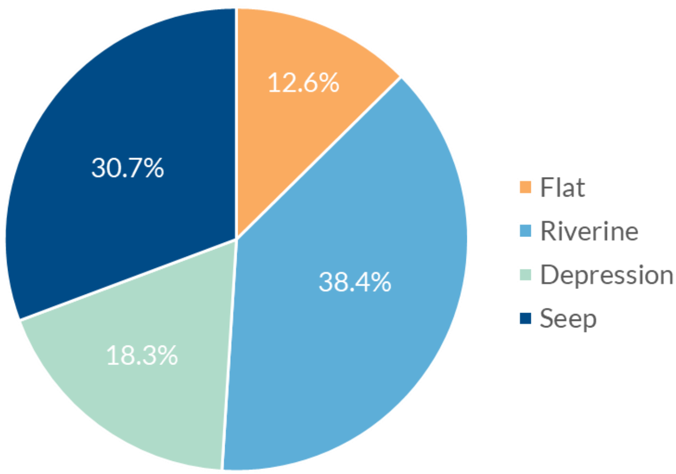


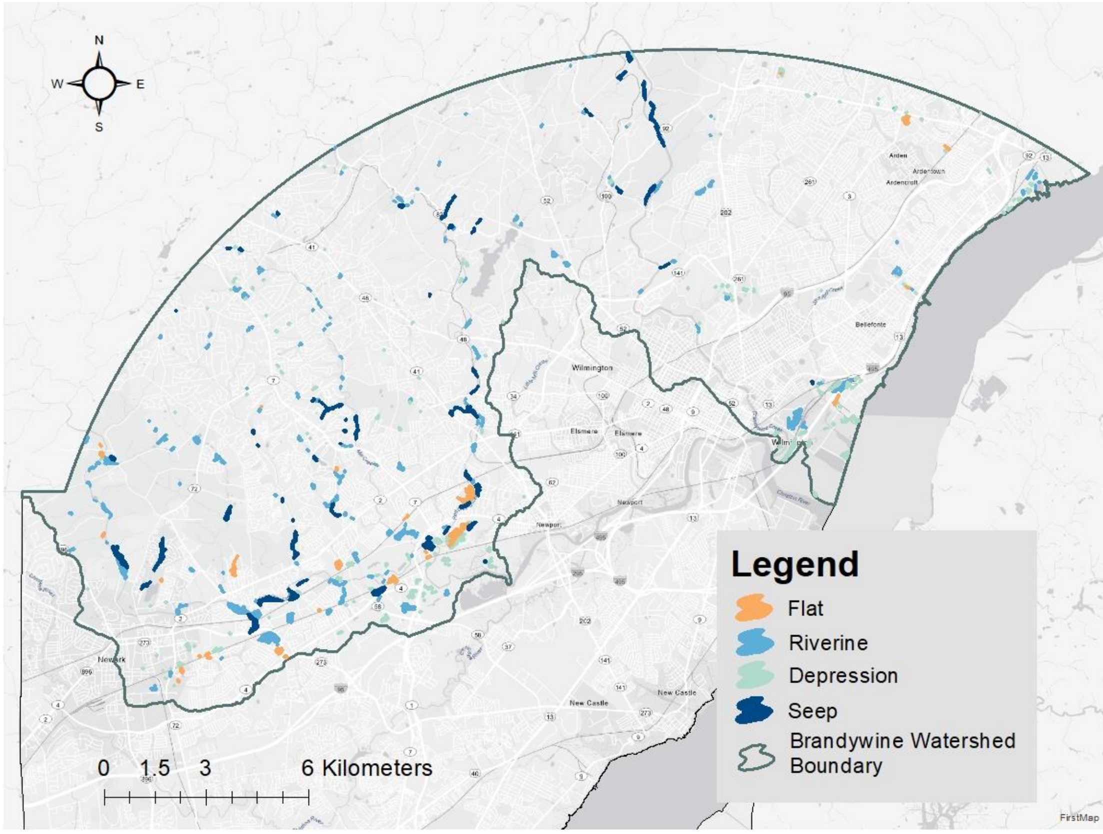
Figure 2. Proportions of major natural wetland types in the Brandywine watershed based on 2017 SWMP maps. Proportions are based on acreage of vegetated wetlands only (non-vegetated wetlands not included).

Today, the Delaware portion of the Piedmont basin, which includes the Brandywine watershed, lies within the Appalachian Piedmont Physiographic Province. The province represents the foothills of the Appalachian Mountains. Just south of the Appalachian Piedmont Physiographic Province is the fall line, which separates it from the Atlantic Coastal Plain Physiographic Province. In the Piedmont area north of the fall line, land is characterized by rolling hills and rocks, while in the Atlantic Coastal Plain area south of the fall line, land tends to be flat, be lower relative to sea-level, and have looser sediments with far fewer large rocks. Most of Delaware lies within the Atlantic Coastal Plain Physiographic Province, making the Piedmont region unique in the state (Delaware Geological Survey 2020).

Wetlands are an extremely important part of the Piedmont Basin. The ecosystem services that wetlands provide within the basin, which includes the Brandywine watershed, have been valued at over $72 million per year, which is equivalent to $11,600 per acre per year (Kauffman 2018). The wetlands within the Brandywine watershed contribute greatly to this total by performing beneficial functions such as water quality improvement, flood control, provision of fish and wildlife habitat, recreation, and carbon sequestration.

According to the 2017 Delaware Statewide Wetland Mapping Project (SWMP), the Brandywine watershed had a total of 2,805.7 acres of wetlands as of 2017, including both vegetated and non-vegetated mapped wetlands. The watershed was composed of 2,272.4 acres of non-tidal wetlands (81.0% of wetlands) and 533.3 acres of tidal wetlands (19.0%). Delaware's Tier 2 wetland condition assessments are conducted only on natural, vegetated wetland types, so those were the focus of the assessments and this report. However, both vegetated and non-vegetated wetland types were evaluated in Tier One landscape assessment and are discussed in acreage trends (see 'Wetland Acreage' in Results section below). Tidal wetlands were not assessed in this watershed because they made up a relatively low proportion of the wetlands in the watershed and they only occurred in two small pockets, meaning that assessment sites would have all been very close together.

The Brandywine watershed had several major types of natural, vegetated, non-tidal wetlands, including flat, riverine, depression, and seep. Flat wetlands are non-tidal wetlands that are often forested and are found in headwater regions that are fed mainly by precipitation. They occur in areas with relatively flat landscapes and poor-draining soils. Riverine wetlands are non-tidal wetlands that are located within the floodplains of rivers and streams. Depression wetlands are non-tidal wetlands that occur in areas of low elevation with little flow that tend to pool water (often seasonally) from groundwater, precipitation, and overland flow. Lastly, seep wetlands are small, non-tidal wetlands that are fed by groundwater that seeps out onto the surface. Some seeps are known as Piedmont seepage swamps, which are closed-canopy wetlands that occur along slopes. Other seeps in the region are called Piedmont seepage meadows, which are mostly open-canopy wetlands that occur along the bases of slopes. Out of the natural, vegetated wetlands in this watershed, the majority were riverine wetlands (300.8 acres; 38.4%) and seeps (240.5 acres; 30.7%), followed by depressions (143.6 acres; 18.3%) and flats (98.7 acres; 12.6%; Figure 2). Most flat wetlands were located in the southwestern part of the watershed, with fewer scattered in the northeast. Riverine and depression wetlands were both scattered throughout the entire watershed, though they had a slightly higher density in the western half. Seeps were largely concentrated in the western half of the watershed (Map 2).



Map 2. Major vegetated wetland types in the Brandywine watershed based on 2017 SWMP data.

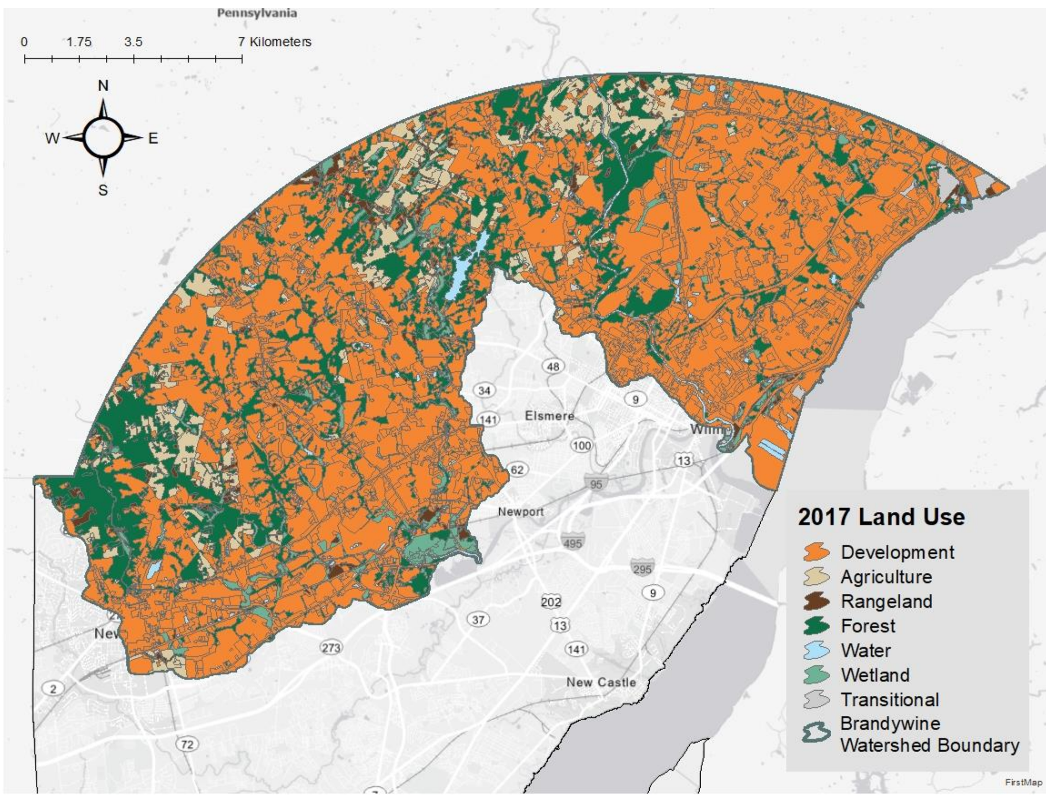
Aquatic bed was the only other type of non-tidal vegetated wetland, but it represented <1% of wetland area in the watershed. Therefore, it was not a target wetland type for assessments. Non-vegetated wetland types included lacustrine unconsolidated bottom and shore, palustrine unconsolidated bottom, and riverine unconsolidated bottom, shore, and stream bed. Delaware's rapid assessment protocols are designed only for vegetated wetland types, so non-vegetated wetlands were not target wetlands and were not sampled in the field (see 'Field Site Selection' in Methods section below).

Land Use and Land Cover

Table 1. Land use and land cover (LULC) change in the Brandywine watershed based on 1997 and 2017 Delaware datasets. Values are percentages. 'Change' represents the change in the percentage of the watershed that a land use category comprises.

Land Use	1997	2017	Change	Main Reasons for Change
Development	64.7	65.5	+ 0.8	Converted forest; converted agricultural land; map reclassifications
Agriculture	9.6	6.8	- 2.8	Residential and recreational development; map reclassifications
Rangeland	0.9	2.2	+ 1.3	Map reclassifications
Forest	21.4	19.9	- 1.5	Converted to development; map reclassifications
Water	1.3	1.7	+ 0.4	New pond and reservoir construction; map reclassifications
Wetlands	0.9	3.4	+ 2.5	Map reclassifications
Transitional	1.2	0.5	- 0.7	Completed development

The most recent land cover dataset for Delaware was from 2017. This land cover dataset showed that the Brandywine watershed was dominated by development (65.5%), followed by forest (19.9%). Smaller portions of land were agriculture (6.8%), wetlands (3.4%), rangeland (2.2%), open water (1.7%), or transitional land that was cleared, likely for future development (0.5%; Table 1). Urban and suburban sprawl was very prominent all over the watershed, particularly in the northeastern and southwestern sections. This was because the watershed is made up of many municipalities, towns, and unincorporated developed areas, including Hockessin, part of Newark, part of Wilmington, Greenville, Arden, Claymont, North Star, Pike Creek, and Ashland. Forest and agriculture were mixed where there were breaks in development in the western and northern parts of the watershed. Areas dominated by forest and agriculture were mainly natural lands, including White Clay Creek State Park, Middle Run Valley Natural Area, Mt. Cuba Center, Auburn Valley State Park, and Brandywine Creek State Park. Wetlands, open water, rangeland, and transitional land were scattered throughout the watershed (Map 3).



Map 3. LULC in the Brandywine watershed based on the 2017 Delaware state land use and land cover data.

Based on a comparison between 1997 and 2017 Delaware land use and land cover datasets, the Brandywine watershed did not experience any substantial land cover changes in the 20-year timeframe. There was a small increase in the amount of development in the watershed, some of which was due to conversion of forest and agricultural land. Consequently, agriculture and forest both made up slightly less of the watershed in

2017 compared with 1997 because some of that land was converted to residential and recreational development. Water cover increased slightly due to new pond and reservoir construction, while transitional land declined because planned roads and developments were completed (Table 1).

However, many changes in land cover type were artifacts of mapping methods, meaning that some land areas were more accurately reclassified from 1997 to 2017. For example, wetlands appeared to make up more of the watershed in 2017 than in 1997 simply because many areas that were incorrectly classified as upland forest, urban land, or open water in 1997 were correctly reclassified as wetlands in 2017 (i.e., land cover did not experience any real changes on the ground). True increases in natural wetland land cover were therefore much smaller than the land cover datasets suggest. This also means that some of the apparent forest and agriculture declines were due to correct land reclassification to development and rangeland, respectively, in mapping. Most changes in rangeland were caused by corrections in mapping from agriculture, forest, and development as well, and some change in water cover was because of corrections in waterway boundaries in mapping. In summary, actual, meaningful changes in the land cover makeup of the watershed were smaller than shown in Table 1, and this was noted for each land use category as 'map reclassifications' under the column 'Main Reasons for Change.'

Surface and Groundwater

Most of Delaware's public water supply comes from groundwater. The Brandywine watershed is an exception, however, because it is one of the only areas in Delaware where the public supply of drinking water comes mostly from surface water. The watershed is home to Hoopes Reservoir, which is the largest reservoir in Delaware and is an important source of public drinking water. Wetlands play an important role in keeping the public water supply clean, as they help filter water and clean out sediments, pollutants, and excess nutrients before it runs into surface waters.

The state of Delaware is required by the EPA to develop a list of impaired waters under Section 303(d) of the Clean Water Act (CWA). Impaired waters are defined as waters that are not meeting clean water criteria even when current existing pollution control strategies (PCSs) are enacted. DNREC performs water quality monitoring throughout the state on a regular basis, allowing them to identify waterbodies that are not meeting water quality standards. States are required to create total maximum daily loads (TMDLs) for certain pollutants of impaired waterbodies, which set limits on the amount of those pollutants that can be discharged into those waterbodies for water quality standards to be met. Several waterbodies within the Brandywine watershed are considered impaired in the state of Delaware under Section 303(d). Naamans Creek and Shellpot Creek have been identified as having high levels of pollutants such as harmful bacteria or excess nitrogen or phosphorus from non-point sources. TMDLs were established for both creeks in 2005 (DNREC 2005a, b). White Clay Creek and Red Clay Creek were both noted as having high zinc levels, largely related to nearby National Vulcanized Fiber (NVF) company facilities. Zinc TMDLs were established in 1999 for both of those creeks (DNREC 1999, 2008), and the Red Clay Creek TMDL was amended in 2009 (DNREC 2008). The EPA also created TMDLs for Brandywine Creek, Red Clay Creek, and White Clay Creek in 2006 for high and low flow nutrient levels as well as for high flow bacteria levels (EPA 2006 a, b, c).

Once TMDLs are developed for impaired waterbodies, the next step is typically to create a PCS, which describes specific actions that can be taken to achieve water quality goals. In Delaware, PCSs are often made by collaboration between DNREC and Tributary Action Teams. Tributary Action Teams are specific to each impaired waterbody or watershed and include a variety of stakeholders, allowing a diverse group of public participants to play a role in the development of PCSs (DNREC n.d.-a). The Brandywine watershed is part of the area that is addressed by the Christina Basin Tributary Action Team, and this team published PCS recommendations in 2011. Some of those recommendations included protecting vegetated open space, implementing a variety of agricultural best management practices (BMPs) such as having cover crops, increasing urban tree canopy and reforesting areas that were once vegetated, and requiring forested riparian buffers around new developments (Delaware Tributary Action Teams et al. 2011).

Category One Wetlands

The Brandywine watershed contained Category One wetlands, which are rare, unique, freshwater wetland types in Delaware. The types of Category One wetlands found in this watershed were Coastal Plain ponds and groundwater seepage wetlands. As previously described, groundwater seepage wetlands, or seeps, are those that occur in areas on slopes or along slope bases where groundwater flows out onto the surface. Groundwater seeps are typically considered riverine or slope wetlands in the HGM classification system. Because of their prevalence in this watershed, seeps were assessed as their own target wetland type. Coastal Plain ponds are relatively small, circular or oval-shaped depressions that are fed by groundwater and precipitation. They are usually flooded in the wet seasons of winter and spring and are often dry on the surface in the summer and fall. Because Coastal Plain ponds are usually classified as depressions in the HGM classification system, they have the potential to be randomly selected for rapid assessments, as depressions are target wetlands.

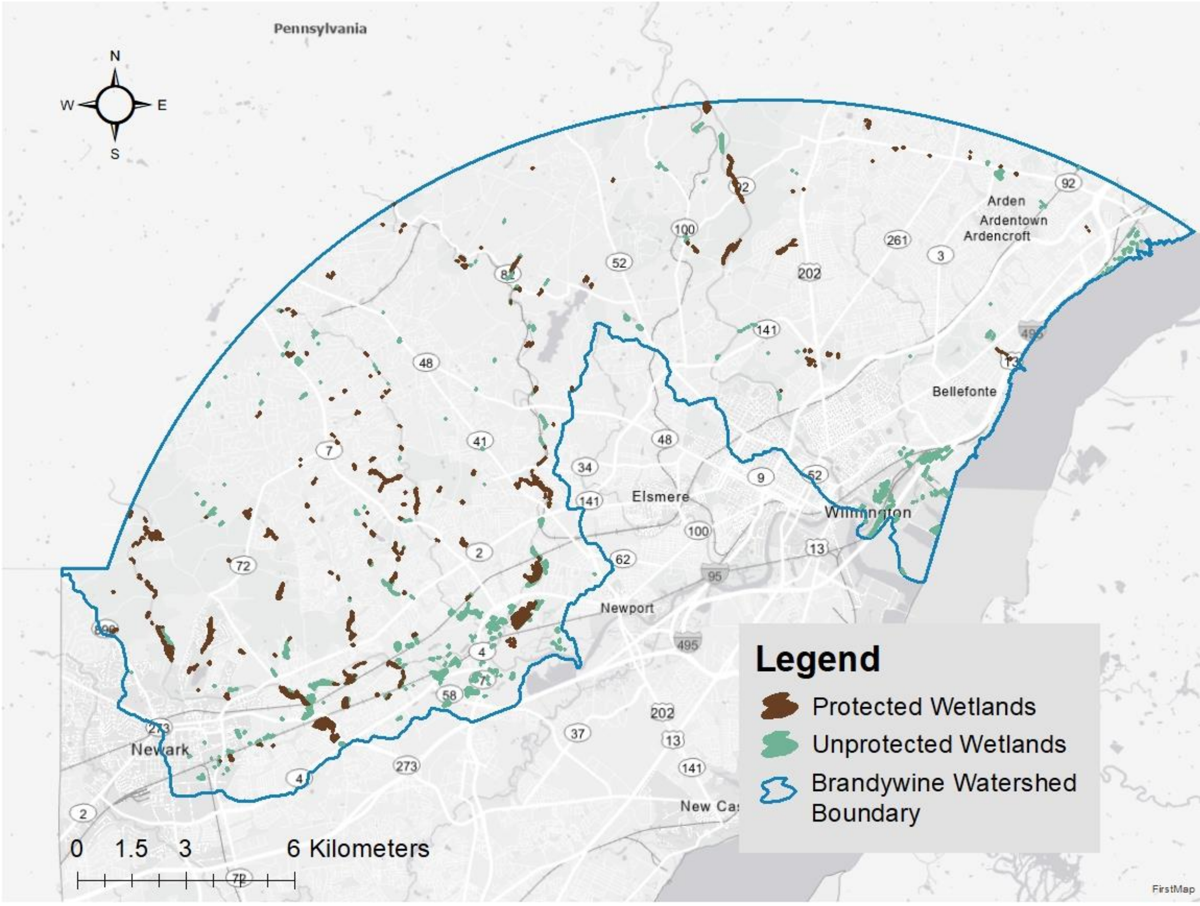
The 2007 and 2017 SWMP maps were used together to estimate Category One wetland acreage because only the 2007 maps included Category One wetland classifications as additional attributes or modifiers, while the 2017 wetland polygons were more accurate. Accuracy checks were performed on polygons with Category One classifications in this watershed using aerial imagery from multiple years and topographic lines. After accuracy checks, it was determined that there were an estimated 240.5 acres of groundwater seeps (as mentioned previously) and only 3.0 acres of Coastal Plain ponds in this watershed.

Protected Areas

Protected areas are lands that are kept natural and are shielded from development. There are various types of protected areas, such as nature preserves, natural areas, open spaces, historical sites, parks, mitigation sites, recreational fields, or conservation easements. According to 2017 SWMP maps and maps of Delaware's protected lands, all protected areas in the watershed combined contained 378.5 acres of vegetated target wetlands, which represented 48.3% of vegetated wetlands in the watershed. Of those protected vegetated wetlands, 61.5 acres were flat wetlands (62.3% of flats), 148.5 acres were riverine wetlands (49.4% of riverine wetlands), 46.1 acres were depression wetlands (32.1% of depressions; Table 2), and 122.4 acres were seep wetlands (50.9% of seeps). Protected wetlands were scattered throughout the watershed, though there was a higher density of protected wetlands in the western half (Map 4).

Table 2. Acres of target wetlands in public or private protected areas as of 2017, and the percentage of each wetland type in protected areas based on the total number of acres of each wetland type in the watershed. Note that seeps are also considered Category One wetlands.

Wetland Type	Acres on Protected Land	Percent of Type on Protected Land
Flat	61.5	62.3
Riverine	148.5	49.4
Depression	46.1	32.1
Seep	122.4	50.9
Total	**378.5**	**48.3**



Map 4. Vegetated, non-tidal wetlands that were on protected and unprotected lands in the Delaware portion of the Brandywine watershed.

The highest proportion of non-tidal, vegetated wetlands on protected land were managed by New Castle County (46.1%; Figure 3), and most of those wetlands were part of land designated as open space or parks. There were also many non-tidal, vegetated wetlands on land that were managed by state agencies (38.5%, Figure 3), including Delaware State Parks and Delaware Department of Transportation (DelDOT). Most wetlands managed by Delaware State Parks were unsurprisingly part of state parks, and those managed by DelDOT were largely on land kept as open space. A much smaller proportion of wetlands were managed by municipalities (7.1%; Figure 3), all of which were parts of open space areas or parks. Private ownership protected 6.7% (Figure 3) of non-tidal vegetated wetlands in the watershed. Such areas were considered historical sites, natural areas, open space land, nature preserves, parks, or conservation easements. The smallest proportion of protected wetlands were on federal land (1.6%; Figure 3) and were managed by the National Park Service (NPS) as part of First State National Historical Park.

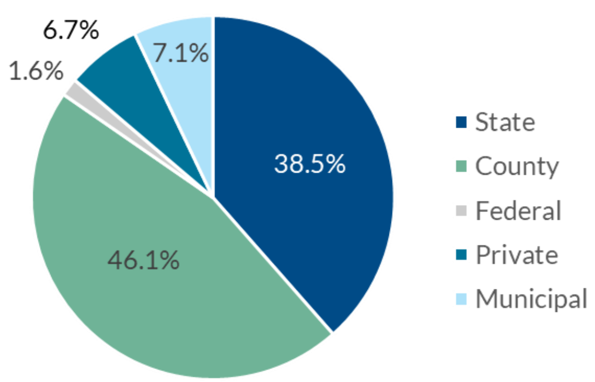


Figure 3. Management of protected, vegetated, non-tidal wetlands in the Brandywine watershed.

Non-tidal wetlands on protected lands are less likely to be degraded by human impacts, so the large portion of non-tidal wetlands that reside within protected areas are relatively safe. However, the more than half of non-tidal wetlands that are not within protected areas are more susceptible to destruction or degradation from human impacts. This is because, as previously mentioned, non-tidal wetlands in Delaware are only regulated by the state if they are greater than 400 contiguous acres, leaving most unregulated. When wetlands are unregulated, they are far more likely to be eliminated or degraded by anthropogenic activity than if a permit were required for their impacts.

Wildlife Habitat and Outdoor Recreation

The 2015 Delaware Wildlife Action Plan (DNREC 2015) highlights wetlands within the Brandywine watershed as important habitats for many reptile and amphibian species of greatest conservation need (SGCN), such as the eastern newt (*Notophthalmus viridescens*) and the bog turtle (*Glyptemys muhlenbergii*; Figure 4). It also identifies wetland types within this watershed as important habitats for bird SGCN, including the Louisiana waterthrush (*Parkesia motacilla*), cerulean warbler (*Setophaga cerulea*), and yellow-throated vireo (*Vireo flavifrons*). Many freshwater mussel and insect SGCN use wetland habitats in this watershed as well, such as the dwarf wedgemussel (*Alasmidonta heterodon*) and the Baltimore checkerspot (*Euphydryas phaeton*; DNREC 2015).

Unique wetlands, such as Category One wetlands, can be particularly important for certain SGCN. Both groundwater seepage wetlands and Coastal Plain ponds, which are unique wetland types found within the Brandywine watershed, are noted as being important for many rare plant and animal SGCN. They are also designated as habitats of conservation concern because they are threatened by factors such as human development, loss of buffers, fragmentation, draining, excess nutrients, and invasion by non-native plants (DNREC 2015), and remain unregulated at the state level.

Figure 4. A bog turtle in a northern Delaware wetland. Photo credit: Holly Niederriter.

Just as wetlands and the areas surrounding them can be important for wildlife, they can also provide many opportunities for outdoor recreation. White Clay Creek State Park, which contains a nationally recognized Wild and Scenic River, is within the Brandywine watershed and has many recreation opportunities, including hiking, biking, fishing, disc golf, and wildlife viewing. Brandywine Creek State Park also lies within the watershed, which offers areas to fish, tube, kayak, and hike. Outdoor enthusiasts can enjoy wildlife viewing, hiking, and biking in Middle Run Valley Natural Area, which is managed by Delaware Nature Society. Plant-lovers can visit the Mt. Cuba Center, which is an outdoor botanical garden that is conservation-minded. Fishing, hiking, and learning about local history can also be enjoyed at First State National Historical Park. At Alapocas Run State Park, visitors can hike, bike, or rock climb.

Wetland Mitigation Spotlight: Glenville

Glenville, now considered a ghost town near Stanton, was the site of a major wetland mitigation bank project in the Brandywine watershed. Glenville was located in an area with severe hydrological alteration, where the original path of the Red Clay Creek had been rerouted and a part of the original channel abandoned back in the early 1700s. The section of abandoned channel was cut off from the creek using fill material such that water no longer flowed in it. Instead, over time, water pooled in the old channel segment and became extremely wet, as water could not drain out into Red Clay Creek. This drainage problem was exacerbated with the construction of a road and an associated culvert to the east of the abandoned channel, as the bottom elevation in the built culvert

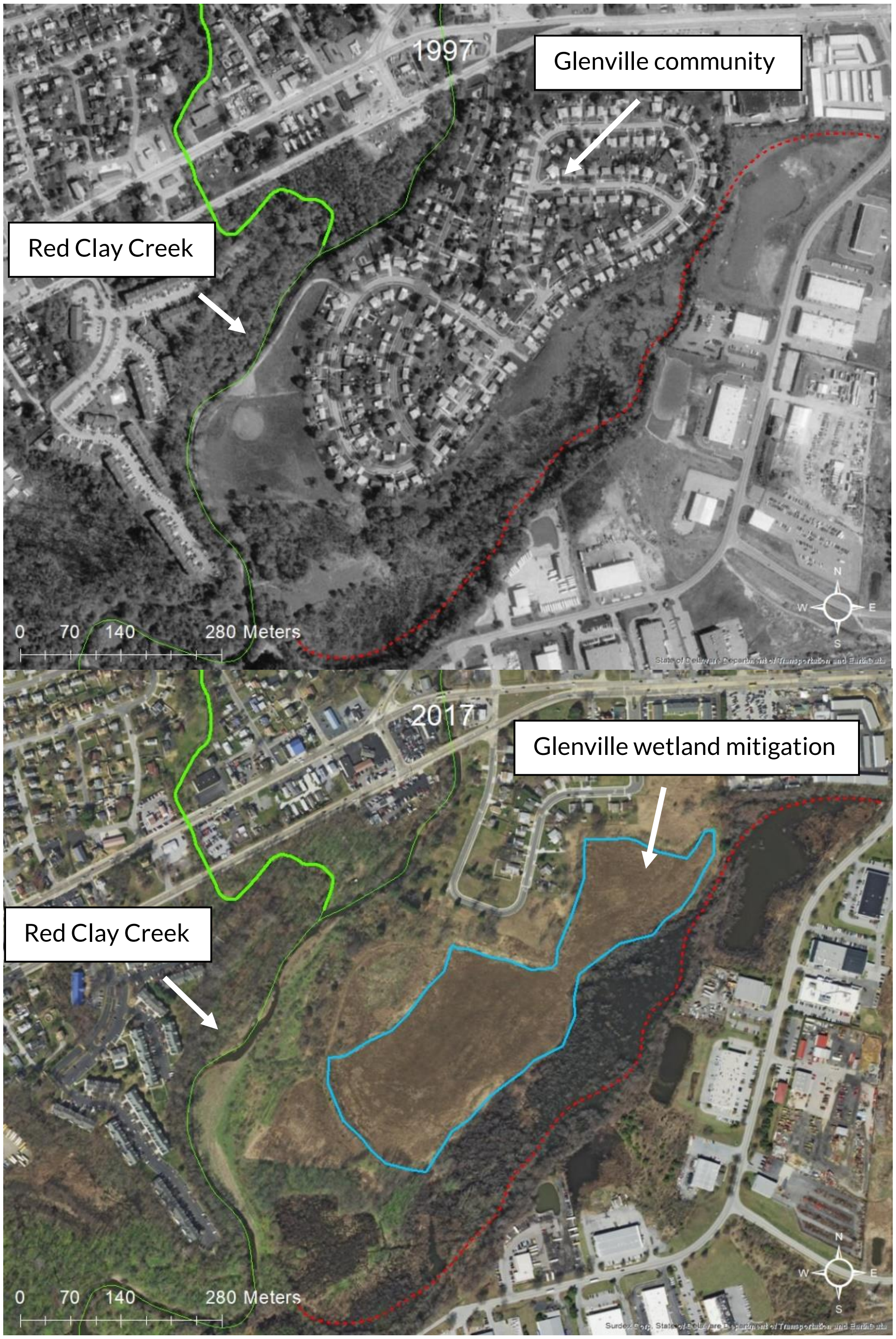


Figure 5. Glenville in 1997 (top) and 2017 (bottom). Bright green lines show streams; the dotted red line shows the historic , disconnected portion of the Red Clay Creek.; and the blue outline shows the approximate boundary of the Glenville wetland mitigation project.

was significantly higher than the bottom elevation of the old channel. As such, water ponded in the old, abandoned channel, where water could only drain out via the culvert, or the initial filled in area, when extreme storm events occurred (DelDOT and Century Engineering 2013).

The Glenville community had a history of flooding problems because of its proximity to the Red Clay Creek; it was constructed within the 100-year floodplain. Flooding could also occur if precipitation was significant enough to cause the old, abandoned channel area to overflow. After a particularly dangerous flood in 2003, the residents of Glenville became extremely alarmed. A public-private partnership was created as DelDOT, the Federal Emergency Management Agency (FEMA), New Castle County, the U.S. Army Corps of Engineers (USACE), DNREC, local residents, and private contractors came together to address the issue. Funding was acquired to buy out over 170 homes within the subdivision, relocate residents, demolish houses, and restore wetlands (Figure 5). The goal of the project was to move residents to safer areas and create wetland habitat with flood storage capacity (DelDOT and Century Engineering 2013, FEMA 2011).

Following the relocation of community residents and destruction of houses, the Glenville Wetland Mitigation Bank was constructed in 2008 and plantings occurred in 2008 and 2009. According to DelDOT and Century Engineering (2013), the wetland was designed to be a forested floodplain wetland that would eventually become a continuation of the existing wetlands of the original, but now abandoned, Red Clay Creek channel to the east. It was also located adjacent to another smaller wetland mitigation project that was previously installed to the south, and an upland/transitional zone was created adjacent to the mitigation wetland along its western border. In total, 19.6 acres of wetlands were created as part of this project (DelDOT and Century Engineering 2013).

Methods

Changes to Wetland Acreage

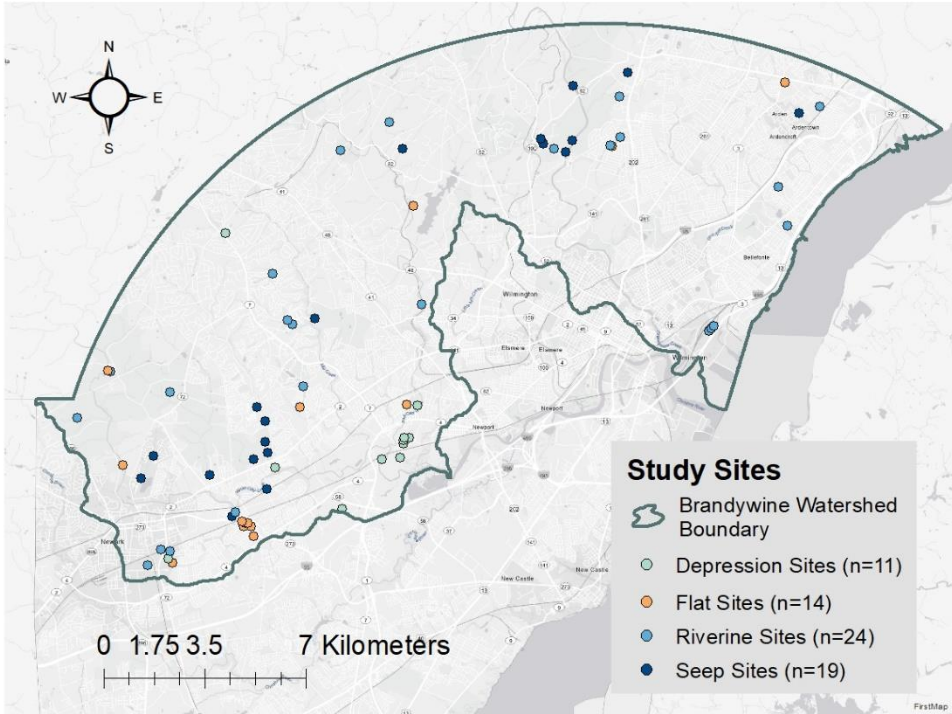
Historic wetland acreage in the Brandywine watershed was estimated using a combination of U.S. Department of Agriculture (USDA) soil maps and historic soil survey maps from 1915. These maps are based on soil indicators such as drainage class, landform, and water flow, and allow for classification of hydric soils. Hydric soils occurring in areas that are currently not classified as wetlands due to significant human impacts, either through urbanization, agriculture, land clearing, or hydrologic alterations, were assumed to be historic wetlands that have been lost prior to 1992. Current wetland acreage was calculated from maps created in 2017 as part of the most recent SWMP mapping effort. More recent trends in wetland acreage were determined from SWMP spatial data, which classified mapped wetland polygons as 'lost', 'gained', or otherwise 'changed' from 1992 to 2007 (Tiner et al. 2011) and from 2007 to 2017 (DNREC 2022). All polygons classified as 'lost', 'gained', or 'changed' were checked using 2007 and 2017 imagery for quality assurance. Both vegetated and non-vegetated wetlands were included in this desktop analysis. Vegetated wetlands were those classified as being dominated by forest, scrub-shrub, emergent, or aquatic bed vegetation. Non-vegetated wetlands were those classified as having little to no vegetation, including unconsolidated bottom or shore.

Field Site Selection

The project goal was to sample 30 non-tidal sites in each main HGM class in the watershed (flat, riverine, depression, and seep) for a total of 120 sites. To accomplish this, the EPA's Ecological Monitoring and Assessment Program (EMAP) in Corvallis, Ore. selected 540 potential sample sites from a target population of non-tidal vegetated wetlands within the Brandywine watershed using the 2007 NWI maps (USFWS 2021). The 2007 maps were used because they were the most recent completed maps available at the time of sampling. EMAP used a generalized random tessellation stratified design, which eliminates selection bias (Stevens and Olsen 1999, 2000). Study sites were randomly-selected points within mapped wetlands, with each point having an equal probability of being selected. There was no stratification in the design. Non-vegetated wetlands and farmed wetlands were not included in the target population and were not assessed because Delaware's wetland condition assessment protocols are only designed to assess natural, vegetated wetlands. Once the full list of potential sample sites was created, sites were considered and sampled in numeric order from lowest to highest, as dictated by the EMAP design. Sites were only dropped from sampling in circumstances that prevented WMAP from accessing the site or if the site was not actually in the target population (see 'Landowner Contact and Site Access' section below for details).

In total, 14 flat, 24 riverine, 11 depression, and 19 seep sites were assessed in the field (Map 5). Statistical survey methods developed by EMAP were then used to extrapolate results from the sampled population of wetland sites to the whole population of those wetlands throughout the watershed (see 'Wetland Condition and Value Data Analysis' section below for details). However, that caution must be used when interpreting extrapolated results for flat, depression, and seep sites, as they had relatively small sample sizes that were much smaller than the goal sample size for each class. One extra riverine site was classified as reference because it was much different than all other riverine wetlands in the watershed and was not considered representative. Three seep sites were assessed as reference sites to gather reference data for the wetland type, as seeps are not common wetland types in any other watershed in Delaware. Reference sites were excluded from statistical analyses.

It should also be acknowledged that four randomly selected wetland assessment sites were within the old, abandoned channel of Red Clay Creek, adjacent to the Glenville wetland mitigation site. As discussed previously (see 'Wetland Mitigation Spotlight: Glenville' in Introduction), this area was once home to the original Red Clay Creek and natural riverine wetlands prior to human settlement. However, in the early 1700s, the Red Clay Creek was diverted along a different path, cutting that section of channel off completely from the creek. Over the course of several hundred years, this wetland area gradually retained more and more water until it became permanently flooded. Today, this wetland area only receives flowing water from other sources when storm events raise water high enough to top the fill that cut the area off from the Red Clay Creek, or when it tops the high-elevation culvert on its northern end. WMAP carefully assessed the four wetland points within the old channel. Despite the fact that the area was once home to natural riverine wetlands hundreds of years ago, and that DelDOT and Century Engineering (2013) considered this area to still be a floodplain wetland, WMAP assessed the four points as depression wetlands based on current topography and water movement. In 2019, when fieldwork was conducted, all four sites more closely resembled depressions than riverine wetlands, with lowest points and deepest water in the center and highest points and shallowest water around the edges. There was also no water movement detected at any site. Additionally, none of those sites were mapped as riverine wetlands on 2007 or 2017 Delaware SWMP maps. This meant that four of 11 depressions assessed, or 36.4%, were in this heavily altered, puzzling area.



Map 5. Locations of study sites by wetland type. Sites were selected using the EMAP sampling design.

Data Collection

Landowner Contact and Site Access

WMAP obtained landowner permission prior to assessing all sites. Landowners were identified using county tax records and each landowner was mailed a postcard providing a brief description of the study goals, sampling techniques, and our contact information. If a contact number was available, the mailings were followed with a phone call to discuss the site visit and secure written permission. If permission was denied, the site was dropped and not visited. Sites were also dropped if a landowner could not be identified or if landowner contact information was unavailable, as those sites were considered inaccessible. Reasonable efforts were made to reach all points, but sites were deemed inaccessible and were subsequently dropped if the site was unsafe to visit for any reason (e.g., severe terrain, deep water, infestation with poisonous plants). Some sites that were selected using the EMAP design were determined upon visitation to be uplands and were subsequently dropped because they were not wetlands. Non-target wetland types, which included any wetlands not considered flat, riverine, depression, or seep, were also dropped.

Assessing Non-tidal Wetland Condition

WMAP used the Delaware Rapid Assessment Procedure (DERAP) v.6.0 to assess the condition of non-tidal wetlands based on the presence and intensity of stressors related to habitat, hydrology, and buffer elements (Table 3; Jacobs 2010). DERAP was followed to collect data at 14 flat sites, 24 riverine sites, 11 depression sites, and 19 seep sites in the Brandywine watershed in summer 2019. Although DERAP was not specifically designed to assess seep wetlands, they were assessed and scored the same way as riverine wetlands. Prior to field assessments, WMAP produced site maps and calculated several buffer metrics within a 100m radius circle around site center points using ArcMap geographic information systems (GIS) software (ESRI 2020). All metrics measured in the office were field verified to confirm accuracy.

Table 3. Metrics measured with the Delaware Rapid Assessment Procedure (DERAP) Version 6.0.

Attribute Group	Metric Name	Description	Measured in AA or Buffer
Habitat	Dominant Forest Age	Estimated age of forest cover class	AA
Habitat	Forest Harvesting within 50 Years	Presence and intensity of selective or clear cutting within 50 years	AA
Habitat	Forest Management	Conversion to pine plantation or evidence of chemical defoliation	AA
Habitat	Vegetation Alteration	Mowing, farming, livestock grazing, or lands otherwise cleared and not recovering	AA
Habitat	Presence of Invasive Species	Presence and abundance of invasive plant cover	AA
Habitat	Excessive Herbivory	Evidence of herbivory or infestation by pine bark beetle, gypsy moth, deer, nutria, etc.	AA
Habitat	Increased Nutrients	Presence of dense algal mats or the abundance of plants indicative of increased nutrients	AA
Habitat	Roads	Non-elevated paths, elevated dirt or gravel roads, or paved roads	AA
Hydrology	Ditches	Depth and abundance of ditches within and adjacent to the AA (flats and depressions only)	AA and Buffer
Hydrology	Stream Alteration	Evidence of stream channelization or natural channel incision (riverine only)	AA
Hydrology	Weir/Dam/Roads	Man-made structures impeding flow of water into or out of the wetland	AA and Buffer
Hydrology	Storm Water Inputs and Point Sources	Evidence of run-off from intensive land use, point source inputs, or sedimentation	AA and Buffer
Hydrology	Filling and/or Excavation	Man-made fill material or the excavation of material	AA
Hydrology	Microtopography Alterations	Alterations to the natural soil surface by forestry operations, tire ruts, and soil subsidence	AA
Buffer	Development	Commercial or residential development and infrastructure	Buffer
Buffer	Roads	Dirt, gravel, or paved roads	Buffer
Buffer	Landfill or Waste Disposal	Reoccurring municipal or private waste disposal	Buffer
Buffer	Channelized Streams or Ditches	Channelized streams or ditches >0.6m deep	Buffer
Buffer	Poultry or Livestock Operation	Poultry or livestock rearing operations	Buffer
Buffer	Forest Harvesting within 15 Years	Evidence of selective or clear cutting within past 15 years	Buffer
Buffer	Golf Course	Presence of a golf course	Buffer
Buffer	Row Crops, Nursery Plants, or Orchards	Agricultural land cover, excluding forestry plantations	Buffer
Buffer	Mowed Area	Any reoccurring activity that inhibits natural succession	Buffer
Buffer	Sand/Gravel Operation	Presence of sand or gravel extraction operations	Buffer

WMAP navigated to the EMAP points in the field with a handheld global positioning system (GPS) unit and established an assessment area (AA) as a 40m radius circle (0.5 ha) centered on each random point (Figure 6). Any necessary adjustments to the AA shape or location were made according to the DERAP protocol (Jacobs 2010). The entire AA was explored on foot and evidence of wetland habitat, hydrology, and buffer stressors (Table 3) were documented during one field visit during the growing season (June 1 to September 30). Field investigators then collectively assigned the wetland a Qualitative Disturbance Rating (QDR) from one (least disturbed) to six (most disturbed; Appendix A) based on best professional judgement upon completion of the field assessment.

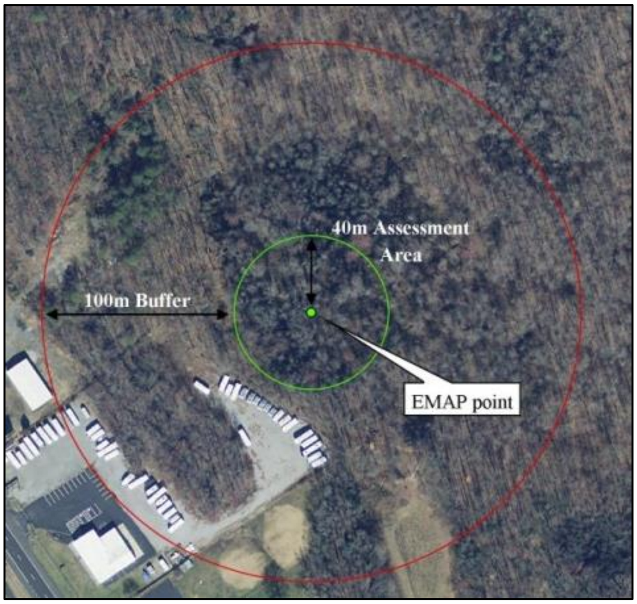


Figure 6. Standard AA (green) and buffer (red) used to collect data for DERAP v.6.0.

DERAP produces one overall wetland condition score for each wetland using a model based on the presence and intensity of the various stressors listed in Table 3 (Appendix B, C; Jacobs 2010). Wetland stressors included in the DERAP model were selected using stepwise multiple regression and Akaike's Information Criteria (AIC) approach to develop the best model that correlated to Delaware Comprehensive Assessment Procedure (DECAP) data (i.e., Tier Three, more detailed assessment data) without over-fitting the model to a specific dataset (Jacobs et al. 2009). Coefficients, or stressor weights, associated with each stressor were assigned using multiple linear regression (Appendix C). This process allowed for effective screening and selection of stressor variables that best represent wetland condition for each HGM class. The DERAP Index of Wetland Condition (IWC) scores were calculated by summing the stressor coefficients for each of the selected stressors that were present and subtracting the sums from the linear regression intercepts for certain HGM types:

$$\textbf{DERAP IWC}_{\textbf{FLATS}} = 95 - (\textstyle\sum \text{stressor weights})$$
$$\textbf{DERAP IWC}_{\textbf{RIVERINE}} = 91 - (\textstyle\sum \text{stressor weights})$$
$$\textbf{DERAP IWC}_{\textbf{DEPRESSION}} = 82 - (\textstyle\sum \text{stressor weights})$$
$$\textbf{DERAP IWC}_{\textbf{SEEP}} = 91 - (\textstyle\sum \text{stressor weights})$$

As shown in these equations, the maximum condition score that a flat wetland can receive is a 95; for riverine and seep wetlands, a 91; and for depression wetlands, an 82.

Example: Site D

Forested flat wetland with 25% of AA clear cut (weight 19), 1-5% invasive plant cover (weight 0), moderate ditching (weight 10), and commercial development in the buffer (weight 3):

DERAP condition score = 95 – (19+0+10+3)

DERAP condition score = 63

Assessing Non-tidal Wetland Value

The local values that wetlands provide may be independent of wetland condition and function (Rogerson and Jennette 2014). Thus, a value-added assessment protocol can provide additional information that, when used in conjunction with condition results from DERAP, can provide managers with a more complete picture for decision making purposes. WMAP performed value-added assessments at non-tidal wetland sites in conjunction with the DERAP assessment using v.1.1 of the Value-Added Assessment Protocol (Rogerson and Jennette 2014). The purpose of this assessment was to evaluate the local ecological value that a wetland provides to the local landscape by assessing seven value metrics (Table 4). Metric scores were tallied to produce a final score that ranged from zero to 100. Categories and category thresholds for final scores are shown in Table 5.

Table 4. Value metrics scored according to v.1.1 of the Value-Added Assessment Protocol.

Value Metric	Description
Uniqueness/Local Significance	Significance of wetland based on ecology and surrounding landscape
Wetland Size	Size of the wetland complex the site falls within
Habitat Availability	Percentage of unfragmented, natural landscape in AA and buffer
Delaware Ecological Network (DEN) Classification	Identification of ecologically important corridors and large blocks of natural areas
Habitat Structure and Complexity	Presence of various habitat features and plant layers important for species diversity and abundance
Flood Storage/Water Quality	Wetland ability to retain water and remove pollutants
Educational Value	Ability of wetland to provide education/recreation opportunities based on public accessibility and aesthetic qualities

Table 5. Categories and thresholds for value-added final scores from v.1.1 of the Value-Added Assessment Protocol.

Value Category	Value Score Range
Rich	≥ 45
Moderate	< 45, ≥ 30
Limited	<30

Wetland Condition and Value Data Analysis

The EMAP sampling method is designed to allow inference about a whole population of resources from a random sample of those resources. In accordance with EMAP design statistical procedures, WMAP used a cumulative distribution function (CDF) to show wetland condition on the population level (Diaz-Ramos et al. 1996). A CDF is a visual tool that extrapolates assessment results from a sample to the entire watershed population. It can be interpreted by drawing a horizontal line anywhere on the graph and reading that as: 'z' proportion of the area of 'x wetland type' in the watershed falls above (or below) the score of 'w' for wetland condition. Points can be placed anywhere on the graph to determine the percent of the population that is within the selected conditions. For example, in Figure 7, approximately 55% of the wetland area scored above 81 for wetland condition. A CDF also highlights cliffs or plateaus where either a large or small portion of wetlands are in similar condition. In the example, there is a condition cliff around 73 and 74, illustrating that a relatively large proportion of the population had condition scores in this range. In contrast, the plateau from about 67 and below indicates that a small proportion of the wetland population scored in this range. When coupled with wetland condition category breakpoints, CDFs can clearly show the percentage of wetlands that fall within each condition category as well. For instance, in the example shown in Figure 7, approximately 55% of wetlands were minimally stressed, 37% were moderately stressed, and 8 % were severely stressed.

Statistical analyses were performed using Microsoft Excel and R version 3.3.0 (R Core Team 2016). Medians of DERAP final scores were calculated in addition to means for this report, as the final scores of riverine wetlands were not normally distributed (Shapiro-Wilk normality test, α=0.05; W=0.84, p<0.01). When data are not normally distributed, the median is a better descriptor of the central tendency of the data than the mean. Flat, depression, and seep DERAP scores were all normally distributed (Shapiro-Wilk normality test, α=0.05; flat: W=0.94, p=0.21; depression: W=0.97, p=0.19; seep: W=0.91, p=0.07), but means and medians are both reported for consistency. All value-added scores were normally distributed (Shapiro-Wilk normality test, α=0.05; flat: W=0.94, p=0.44; riverine: W=0.98, p=0.79; depression: W=0.90, p=0.19; seep: W=0.93, p=0.18), but means and medians are both still reported for consistency.

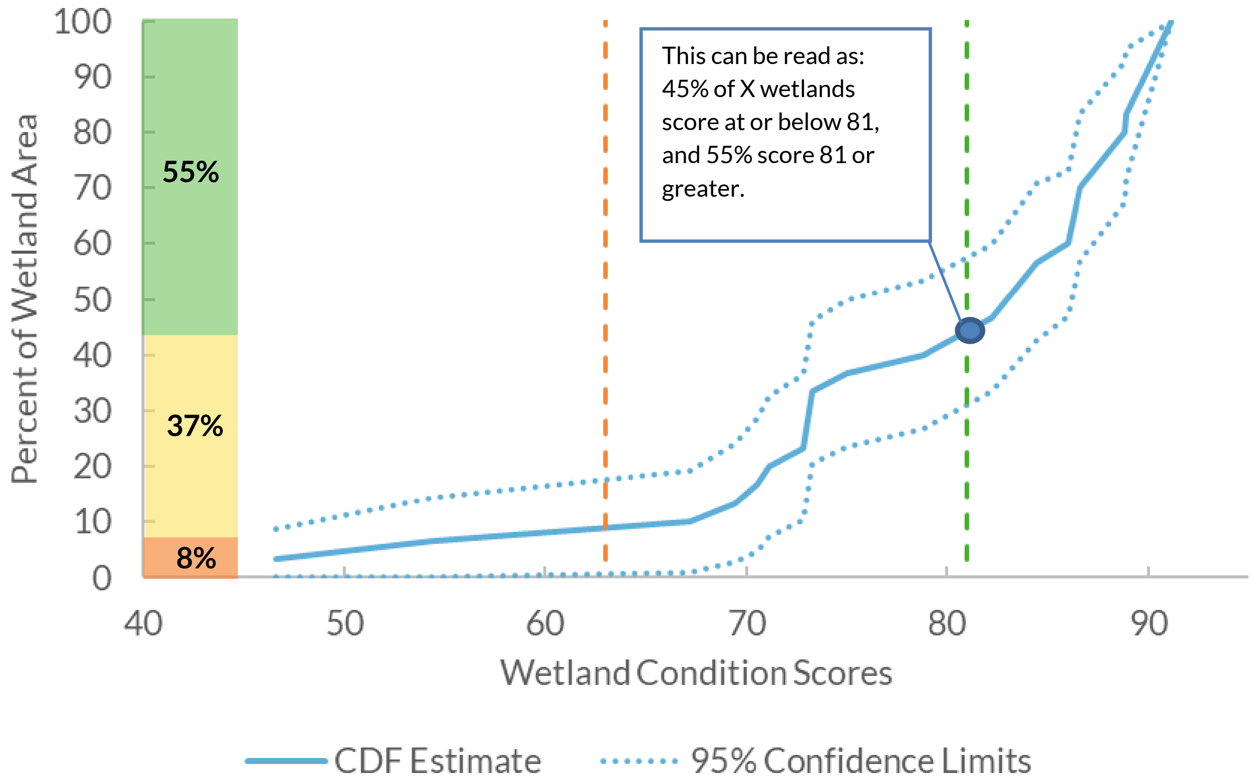


Figure 7. An example CDF showing wetland condition. The solid blue line is the population estimate and the dashed blue lines are 95% confidence intervals. Colored blocks on the y-axis show percent of wetlands within each condition category, where orange is severely stressed, yellow is moderately stressed, and green is minimally stressed. The orange and green dashed lines show breakpoints between condition categories.

Sites in each HGM class were placed into three condition categories: minimally stressed, moderately stressed, or severely stressed (Table 6). Condition class breakpoints were determined by applying a percentile calculation to the QDRs and condition scores from sites in several watersheds that were assessed previously (Jacobs 2010). Minimally stressed sites are those with a condition score greater than the 25th percentile of sites assigned a QDR of one or two. Severely stressed sites are those with a condition score less than the 75th percentile of sites assigned a QDR of five or six. Moderately stressed sites are those that fall in between.

Table 6. Condition categories and breakpoint values for non-tidal wetlands in the Brandywine watershed as determined by wetland condition scores, where 'x' denotes a condition score in each listed inequality.

Wetland Type	Method	Minimally Stressed	Moderately Stressed	Severely Stressed
Flat	DERAP	x ≥ 88	88 > x ≥ 65	x < 65
Riverine	DERAP	x ≥ 85	85 > x ≥ 47	x < 47
Depression	DERAP	x ≥ 73	73 > x ≥ 53	x < 53
Seep	DERAP	x ≥ 85	85 > x ≥ 47	x < 47

Wetland Health Report Card

Information in this technical report was used to create a wetland health report card. The report card provides a clear, concise summary of wetland health and management recommendations in the Brandywine watershed for the general public. It is publicly available online (see pg. 54 for link). In the report card, wetland health is portrayed in a symbolic and colorful manner to make the data clear and understandable for the general public. This involved converting wetland health scores from this report into letter grades, symbols, and color-coded health categories.

Letter grades (A - F) were assigned to each wetland type based on condition scores, with A being the highest grade for wetlands in the best health, and F being the lowest grade for wetlands in the worst health. These overall grades were calculated by dividing average final DERAP scores for each HGM type by the maximum possible DERAP score for each type. Flat wetlands achieved a letter grade of B-; riverine wetlands, a C; depressions wetlands, a C; and seep wetlands, a B-. The whole watershed was assigned a letter grade of C+, which was calculated by multiplying overall report card grades for each wetland type by the acreage proportion for each type in the watershed (i.e., weighting based on acreage), and then summing those values. All report card grades are listed in Table 7, and the letter grade scale used can be seen in Appendix D.

Table 7. Report card grades by wetland type and overall watershed. Grades are listed as final overall grades for each type, as well as by attribute category.

Wetland Type	Overall Grade	Habitat Grade	Hydrology Grade	Buffer Grade
Flat	**B-**	A	C+	D
Riverine	**C**	B-	B+	D
Depression	**C**	B-	A-	C
Seep	**B-**	B-	A-	C
Overall Watershed	**C+**	.	.	.

The habitat and hydrology attribute categories for each non-tidal wetland type were also given letter grades by dividing total stressor weight sums for each category by the total possible stressor category weight sum, and then converting it to a zero to 100 scale. Letter grades were assigned to non-tidal buffers by averaging the buffer stressor tally for each wetland type (i.e., the number of buffer stressors rather than stressor weights) and comparing that average to a grading scale that was designed specifically for non-tidal buffers (see Appendix D). The symbols used in the report card to depict habitat, hydrology, and buffer were also used in the results section (see 'Results' below) of this report (Table 8).

Table 8. Symbols and their meanings for each attribute category.

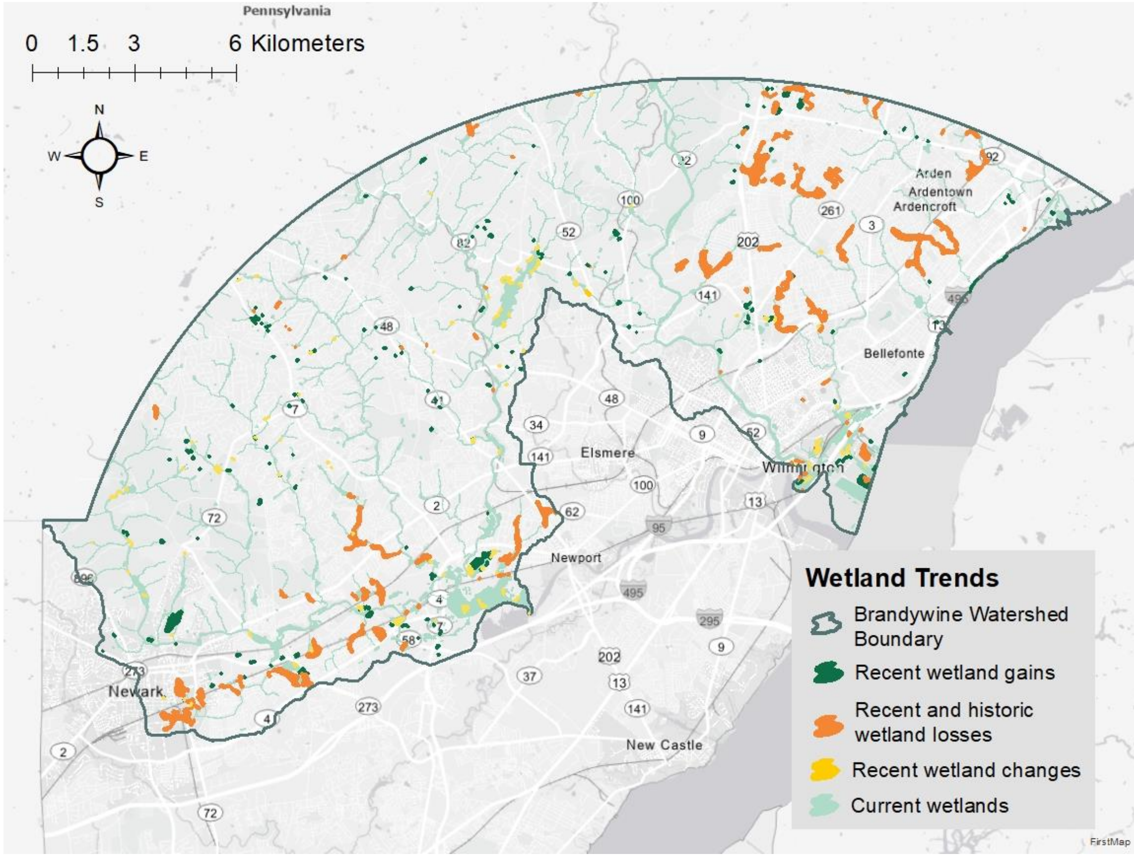
Category	Symbol
Habitat	
Hydrology	
Buffer	

Results

Wetland Acreage

The Brandywine watershed contained an estimated 3,784 acres of wetlands prior to human settlement in the early 1700s. Approximately 936 acres were lost or destroyed prior to 1992, while an additional 42 acres were lost more recently between 1992 and 2017. Altogether, this indicates that about 26% of historic wetland acreage has been lost in this watershed up to 2017. These wetland losses were due primarily to human development, mainly in the northeast and southwest parts of the watershed (Map 6, Table 9).

Recent wetland losses that occurred between 1992 and 2017 amounted to 41.8 acres (Table 9). Of that total, 27.7 acres (66.3%) were vegetated wetlands, and 14.1 acres (33.7%) were non-vegetated. Most vegetated losses were that of riverine and depression wetlands, which were destroyed by development, road and parking lot construction, and golf course construction (see example in Figure 8). Fewer flat wetlands were lost, and those that were lost were eliminated due to the same reasons as riverine and depression wetlands. Non-vegetated wetlands that were lost were excavated or impounded ponds that were filled in for development. According to wetland maps, no groundwater seep losses occurred during this 25-year time period; however, seeps are often small wetlands that are difficult to map, and as such, there may have been losses that were undetected.



Map 6. Wetland trends over time in the Brandywine watershed. Recent wetland type changes and wetland acreage gains are those that occurred between 1992 and 2017. Historic and recent wetland losses are all estimated losses that occurred over time up to 2017. Current wetlands include all vegetated and non-vegetated wetlands as of 2017.

Table 9. Recent wetland acreage gains and losses in the Brandywine watershed between 1992 and 2017.

Wetland Type	Gain (acres)	Loss (acres)
Flat	22.5	2.7
Riverine	0.8	14.6
Depression	10.5	10.4
Seep	0.0	0.0
Non-vegetated Pond	128.5	14.1
Total	162.3	41.8

In the same time frame, the Brandywine watershed gained 162.3 acres of wetlands, which was more than was lost (Table 9). This resulted in an overall watershed net gain of 120.5 acres. Most gained wetlands were non-vegetated ponds or pond edges (128.5 acres; 79.2% of gains) that were excavated or impounded. This means that despite an overall net wetland acreage gain in the watershed, wetland functional gain was likely limited, as created, non-vegetated wetlands typically provide fewer ecosystem services than natural, vegetated wetlands.

There were some vegetated wetland gains from 1992 to 2017, amounting to 33.8 acres (20.8% of gains). Most of those were flats, followed by depressions and riverine wetlands. A majority of such vegetated wetlands appeared manmade in imagery, while fewer were once impacted by anthropogenic activity and have since begun to recover. Notably, nearly all gained flat wetland acreage (20.2 acres; 89.8% of gained flat acreage) was the result of the large wetland mitigation project in Glenville. No seeps were gained in recent years.

Table 10. Recent wetland type changes in the Brandywine watershed between 1992 and 2017.

Change Type	Acres
Non-vegetated to vegetated	23.4
Vegetated to non-vegetated	10.9
Succession	9.7
Clearing	14.0
Non-vegetated to other non-vegetated habitat type	5.6
Marsh migration	3.2
Total	66.8

Figure 8. An example of a wetland loss that occurred in the Brandywine watershed between 1992 and 2007. In 1992 (top), there was a forested wetland present, outlined in orange. By 2007 (bottom), the wetland was lost to road construction.

A total of 66.8 acres were classified as 'changed' in the Brandywine watershed between 1992 and 2017 (Map 6, Table 10). Such areas changed from one wetland type to another within that time frame. Many documented changes were that of non-vegetated wetlands becoming vegetated (23.4 acres; 35.0% of changes). Other changes were the exact opposite, where vegetated wetlands lost vegetation during the 25-year time frame (10.9 acres; 16.3% of changes). Both of these types of changes mainly occurred in residential or golf course ponds and was likely the result of changing water levels in the ponds over time. Succession altered the dominant vegetation type in 9.7 acres (14.5% of changes) of wetlands, meaning that emergent plants gave way to scrub-shrub or forest habitat. Anthropogenic alteration or clearing affected 14.0 acres (21.0% of changes) of wetlands. Those types of changes resulted in forest or scrub-shrub habitat reverting to emergent. Fewer wetland changes involved one non-vegetated type morphing into a different non-vegetated type (5.6 acres; 8.4% of changes), such as unconsolidated bottom to shore. Those changes all occurred along the edges of Hoopes Reservoir. Marsh migration caused changes to 3.2 acres (4.8% of changes) of wetlands, where forested wetland died back and gave way to tidal marsh.

Landowner Contact and Site Access

In total, 328 non-tidal sites were considered, where 256 sites were dropped (78.0%) and 72 sites were sampled (22.0%). Four of the 72 sites that were assessed were reference sites; data was collected there, but reference sites were omitted from condition analyses. Most sites were dropped because they were found not to be wetlands upon visitation in the field (44.2%). This was a reflection of how inaccurate the 2007 wetland maps were in the hilly watershed (recall that 2007 SWMP maps were used to select field sites; see 'Field Site Selection' in Methods for details). For example, many wetland polygons where sample points were located were classified as flats on maps, but upon field visitation, were steeply sloped and were not wetlands. Many sites were also dropped because they were inaccessible (26.8%), either because landowners could not be reached or because of safety concerns. Far fewer sites were dropped because permission to access them was denied (5.8%) or because they were non-target wetland types (1.2%; Figure 9).

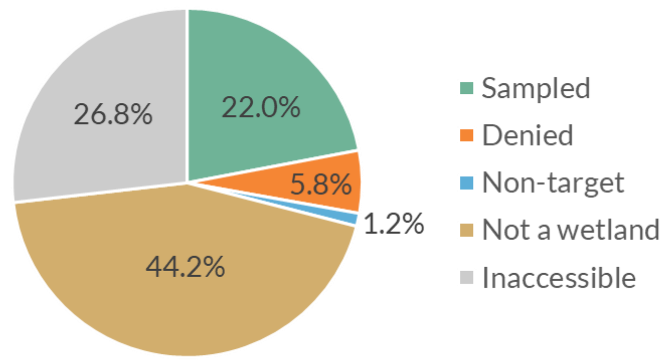


Figure 9. Sampling success for non-tidal wetlands in the Brandywine watershed. Shown are percentages of the total number of sites where sampling was attempted (n=328).

A total of 68 wetland sites were assessed and analyzed in the Brandywine watershed. Wetland ownership was close to even, with 52.9% publicly owned and 47.1% privately owned. Ownership percentages varied by wetland type. Riverine wetlands had slightly higher public ownership (54.2%) than private ownership (45.8%). Depression wetlands showed a very similar pattern, with 54.5% publicly owned and 45.5% privately owned. Nearly two-thirds of flats (64.3%) were privately owned and 35.7% were publicly owned. Seeps were the opposite of flats, where nearly two-thirds (63.2%) were publicly owned and 36.8% were privately owned (Table 11).

Table 11. Ownership of wetland sites that were assessed and analyzed in the Brandywine watershed (n=68; does not include reference sites).

Wetland Type	Public (%)	Private (%)
Flat	35.7	64.3
Riverine	54.2	45.8
Depression	54.5	45.5
Seep	63.2	36.8
All combined	**52.9**	**47.1**

Wetland Condition and Value

Non-tidal Flat Wetlands

There were 14 sampled flat wetlands (n=14) in the Brandywine watershed (Figure 10), far fewer than the goal of 30 sample sites. This was because flats turned out to be uncommon on the landscape when conducting assessments and field-verifying mapping classifications. Sample data were still extrapolated to the entire population of flat wetlands in the watershed, but caution should be exercised in this interpretation, keeping in mind the small sample size.

All flats had mineral soils. Most flats (85.7%) were in old growth forests, with tree age estimated to be >50 years old; all others were forested, but younger. Common native species in these wetlands were greenbriar

Figure 10. A flat wetland in the Brandywine watershed.

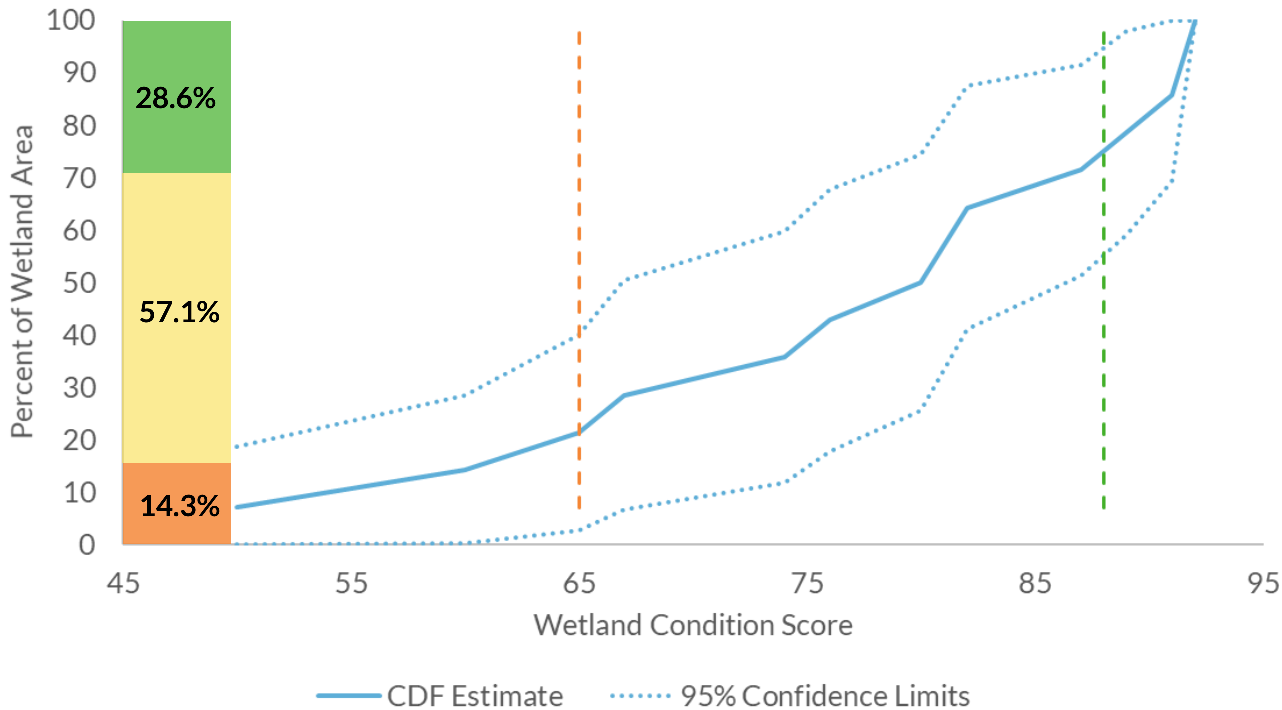


Figure 11. Cumulative distribution function (CDF) for non-tidal flat wetlands in the Brandywine watershed. The solid blue line is the population estimate and the dashed blue lines are 95% confidence intervals. Colored blocks on the y-axis show percent of wetlands within each condition category, where orange is severely stressed, yellow is moderately stressed, and green is minimally stressed. The orange and green dashed lines show breakpoints between condition categories.

(*Smilax rotundifolia*), sweet gum (*Liquidambar styraciflua*), sweet pepperbush (*Clethra alnifolia*), poison ivy (*Toxicodendron radicans*), black gum (*Nyssa sylvatica*), tulip poplar (*Liriodendron tulipifera*), and red maple (*Acer rubrum*). Flats had final DERAP scores that ranged from 50.0 to 92.0, with a mean score of 77.6 ± 13.1 (median=81.0) out of a maximum possible score of 95.0. The highest proportion of flats was moderately stressed (57.1%), followed by minimally stressed (28.6%) and severely stressed (14.3%; Figure 11). Minimally stressed flats were predominantly affected by invasive species and fill within them and development and roads in the surrounding landscape. In addition to those stressors, moderately and severely stressed wetlands were commonly ditched and often had mowing and channelized streams or ditches in the surrounding landscape (Table 12). Data for all sampled flat wetlands for all assessed metrics can be viewed in Appendix E.

The most common habitat stressor found in flat wetlands was invasive species (Table 12). Invasive species that were detected included Japanese stiltgrass (*Microstegium vimineum*), Japanese honeysuckle (*Lonicera japonica*), mulitflora rose (*Rosa multiflora*), English ivy (*Hedera helix*), mile-a-minute (*Persicaria perfoliate*), reed canary grass (*Phalaris arundinacea*), European privet (*Ligustrum vulgare*), and stinging nettle (*Urtica dioica*). Invasive species were present in 100% of flats, where 21.4% of flats had >50% coverage of invasive species and 78.6% of flats had <50% coverage. Other habitat stressors were uncommon in flats. Forest harvesting was only detected in 7.1% of wetlands and mowing was found in 14.3%. No pine plantations, chemical defoliation, excessive herbivory, dense algal mats, or any other form of vegetation alteration occurred in flats in this watershed.

Ditching was one of the most widespread hydrology stressors (Table 12), and of flats that were ditched, 57.1% were slight ditches (shallow and conveying little water), 14.3% were moderate, and 28.6% were severe. Fill was also common, most of which occurred on <10% of the wetland area (85.7% of flats with fill) and the rest of which occurred on 10 - 75% of the wetland area. Less common hydrology stressors included stormwater inputs and microtopographic alterations, which were found in 14.3% of flats. No weirs, dams, or roads, point sources, or excessive sedimentation were present in any flat wetlands.

Table 12. Listed are the most common stressors (>20% occurrence) in flat wetlands (see Table 8 for symbol category meanings). Also shown are the occurrence of stressors in each condition category (%min = % minimally stressed; %mod = % moderately stressed; %sev = % severely stressed).

Category	Stressor	% Total (n=14)	% Min (n=4)	% Mod (n=8)	% Sev (n=2)
	Invasive species	100.0	100.0	100.0	100.0
	Ditching	50.0	0.0	75.0	50.0
	Fill	50.0	25.0	50.0	100.0
	Development in surrounding landscape	64.3	50.0	62.5	100.0
	Roads in surrounding landscape	64.3	50.0	62.5	100.0
	Mowing in surrounding landscape	28.6	0.0	25.0	100.0
	Channelized streams or ditches in surrounding landscape	21.4	0.0	25.0	50.0

Buffer stressors were widespread around flat wetlands in the Brandywine watershed. The most common buffer stressors in landscapes surrounding flats were development, roads, mowing, and channelized streams or ditches in the surrounding landscape (Table 12). Most development around wetlands was residential and most roads were two-lane roads. Agriculture was far less common and was found nearby 7.1% of flat wetlands. Landfill or waste disposal operations, poultry or livestock operations, recent forest harvesting, golf courses, and sand or gravel operations were not found in landscapes surrounding flats.

Half of flat wetlands were classified as providing limited value and the other half as providing moderate value, while no flats were rated as providing rich value (Figure 12). Flat wetlands provided some value in terms of habitat availability; on average, 73.9% ± 23.0% of the area within flat wetland buffers was natural and unfragmented. They also offered some value through habitat structure and complexity and being part of the DEN network. The most common habitat features found within flats were coarse woody debris, tree and herbaceous cover, shrub and sapling cover, large downed wood, and snags. Half of flat wetlands were located entirely, with buffers partially, within the DEN network. This means that many flats, and parts of their buffer areas, were within large corridors of ecologically important natural land. In addition, flats offered some value related to flood storage and water quality. This was mainly because a large proportion of flats were rated as providing moderate to high sediment retention (78.6%), and some were also adjacent to surface waters (35.7%) or had evidence of water pooling on the surface (35.7%).

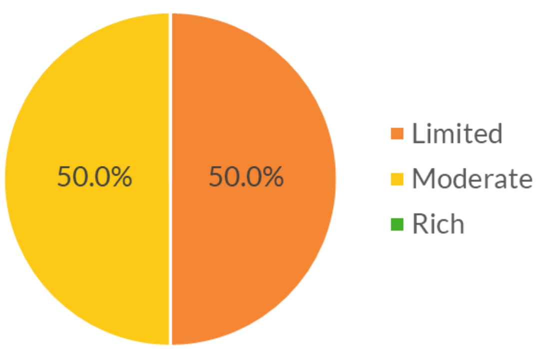


Figure 12. Proportion of flat wetlands in each value-added category.

Flats were rated as providing very little value in education potential because few were viewable from public roads, had parking for more than two vehicles, or had trail systems or boardwalks. Additionally, flat wetlands offered very little value for wetland size, as most were relatively small in this watershed (average size 10.9 ha ± 3.8 ha). Flat wetlands in this watershed provided no value in terms of uniqueness or significance, as none sampled were classified as being rare in the landscape or as being restored, established, or enhanced wetlands.

Non-tidal Riverine Wetlands

Twenty-four (n=24) riverine wetlands were assessed in the Brandywine watershed (Figure 13), close to the goal of 30 sample sites. Riverine wetlands were classified as being along a mix of upper and lower perennial streams. Most (75.0%) were in old growth forests, with average tree age estimated to be >50 years old. Common native species in Brandywine riverine wetlands included red maple (*A. rubrum*), poison ivy (*T. radicans*), sweet gum (*L. styraciflua*), skunk cabbage (*Symplocarpus foetidus*), jewelweed (*Impatiens capensis*), greenbriar (*S. rotundifolia*), rice cutgrass (*Leersia oryzoides*), and false nettle (*Boehmeria cylindrica*). Riverine wetlands had final DERAP scores that ranged widely from 26.0 to 85.0, with a mean score of 68.4 ± 15.9 (median=68.0) out of a maximum possible score of 91.0. The highest proportion of these wetlands was moderately stressed (79.2%), followed by severely stressed (12.5%) and minimally stressed (8.3%; Figure 14). Minimally stressed riverine wetlands were

Figure 13. A stream and associated riverine wetland in the Brandywine watershed.

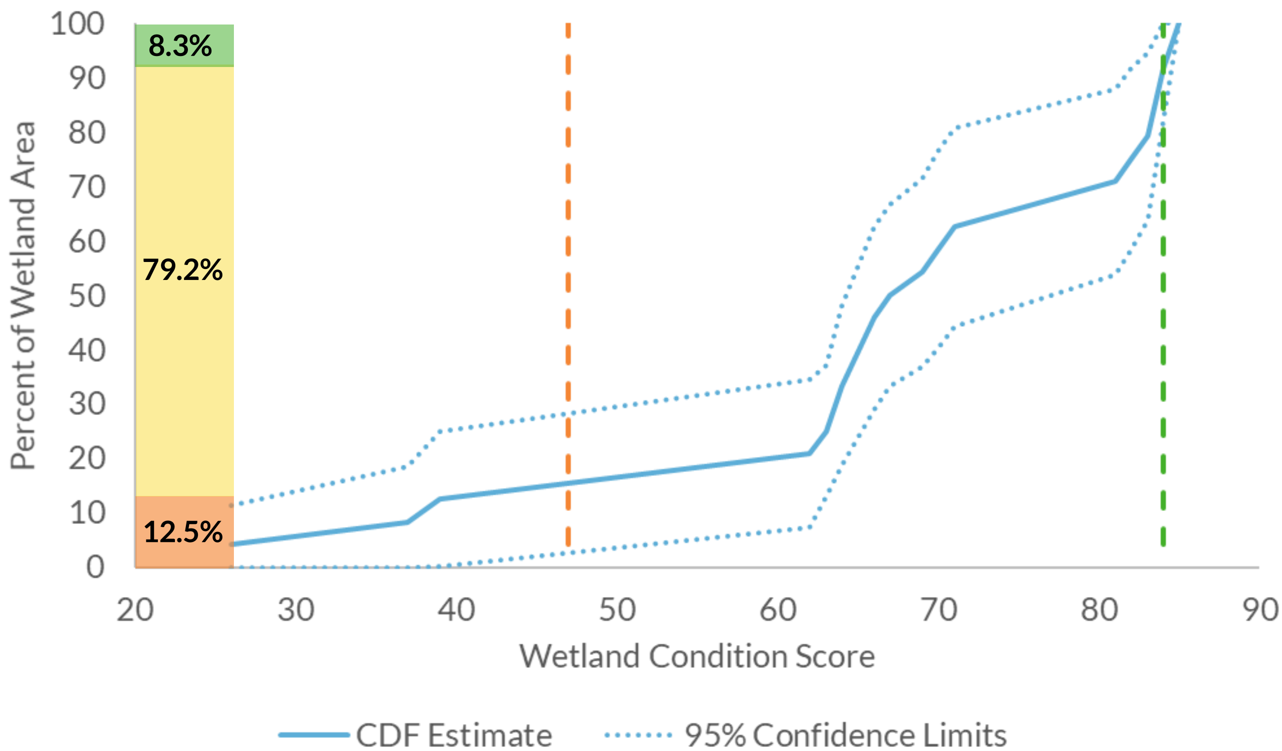


Figure 14. Cumulative distribution function (CDF) for non-tidal riverine wetlands in the Brandywine watershed. The solid blue line is the population estimate and the dashed blue lines are 95% confidence intervals. Colored blocks on the y-axis show percent of wetlands within each condition category, where orange is severely stressed, yellow is moderately stressed, and green is minimally stressed. The orange and green dashed lines show breakpoints between condition categories.

mostly affected by invasive species, development in the surrounding landscape, and mowing in the surrounding landscape. In addition to those same stressors, moderately and severely stressed riverine wetlands were also affected by weirs, dams, or roads in the wetlands, stormwater inputs, fill in the wetlands, and roads in the surrounding landscape (Table 13). Data for all sampled riverine wetlands for all assessed metrics can be viewed in Appendix F.

The presence of invasive plant species was the most widespread of all stressors and was the most common habitat stressor (Table 13). Most (52.6%) had 6 - 50% cover (33.3%) or >50% cover (33.3%), followed by 1 - 5% cover (29.2%) and <1% cover (4.2%). Invasive species that were detected were multiflora rose (*R. multiflora*), Japanese stiltgrass (*M. vimineum*), Japanese honeysuckle (*L. japonica*), European reed (*Phragmites australis australis*), English ivy (*H. helix*), stinging nettle (*U. dioica*), mile-a-minute (*P. perfoliata*), narrowleaf cattail (*Typha angustifolia*), autumn olive (*Elaeagnus umbellata*), Japanese hops (*Humulus japonicus*), European privet (*L. vulgare*), Japanese barberry (*Berberis thunbergii*), and hydrilla (*Hydrilla verticillata*). Other habitat stressors that were less common were selective tree cutting (4.2% of riverine wetlands), clear cutting over 50% of the wetland area (4.2%), mowing (4.2%), and roads (8.3%). Pine plantations, chemical defoliation, excessive herbivory, dense algal mats, or other vegetation alterations were absent from riverine wetlands in this watershed.

Table 13. Listed are the most common stressors (>20% occurrence) in riverine wetlands (see Table 8 for symbol category meanings). Also shown are the occurrence of stressors in each condition category (%min = % minimally stressed; %mod = % moderately stressed; %sev = % severely stressed).

Category	Stressor	% Total (n=24)	% Min (n=2)	% Mod (n=19)	% Sev (n=3)
	Invasive species	100.0	100.0	100.0	100.0
	Weirs/Dams/Roads	29.2	0.0	26.3	66.7
	Stormwater inputs	29.2	0.0	26.3	66.7
	Fill	20.8	0.0	15.8	66.7
	Development in surrounding landscape	66.7	50.0	68.4	66.7
	Mowing in surrounding landscape	66.7	50.0	63.2	100.0
	Roads in surrounding landscape	54.2	0.0	57.9	66.7

The most prevalent hydrology stressors were weirs, dams, or roads, and stormwater inputs, which were found in 29.2% of riverine wetlands. When present, weirs, dams, or roads either decreased flooding in the wetlands or impounded water. Fill was also a significant stressor found in 20.8% of wetlands (Table 13), though the amount of fill detected ranged widely from 0 - 75% of the wetland area when detected. Stream channelization was present in fewer riverine wetlands (12.5%). Point sources, excessive sedimentation, and microtopographic alterations were absent from riverine wetlands in this watershed.

Riverine wetlands had a wide variety of buffer stressors, and the most predominant were development, mowing, and roads. Development was found around 66.7% of riverine wetlands and was a mix of commercial or industrial and residential development. Mowing was also found around 66.7% of wetlands, while roads were present surrounding 54.2% of them (Table 13). Road types ranged from dirt or gravel to two- or four-lane highways. Agriculture was a less common buffer stressor only found around 8.3% of riverine wetlands, and poultry or livestock operations and recent forest harvesting were both even scarcer, each only near 4.2% of wetlands. Golf courses, landfills or waste disposal, channelized streams or ditches, and sand or gravel operations were all absent around riverine wetlands in this watershed.

Most riverine wetlands in this watershed provided limited value to people and wildlife (45.8%), followed closely by moderate value (41.7%), and then by rich value (12.5%; Figure 15). Of the attributes assessed, riverine wetlands offered the most value in habitat structure and complexity and in flood storage and water quality. Common habitat features present in riverine wetlands that were beneficial for wildlife included herbaceous and tree cover, tree gaps, course woody debris, and water for fish and amphibians. All riverine wetlands were adjacent to surface waters, and many showed evidence of stormflow and were rated as having moderate to high sediment retention capabilities, making them valuable for storing and cleaning flood waters.

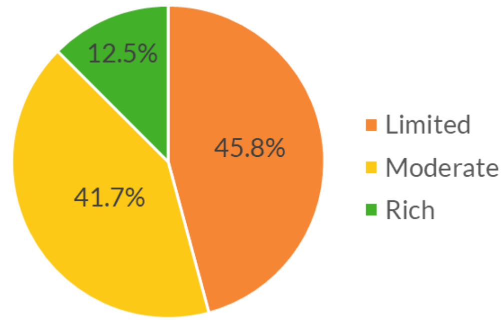


Figure 15. Proportion of riverine wetlands in each value-added category.

Riverine wetlands also provided some value in terms of connectivity and habitat availability. Some wetlands and their buffer areas were entirely or partially within the DEN network of ecologically significant corridors. On average, 72.1 ± 20.2% of buffer area around riverine wetlands was natural and unfragmented. In contrast, riverine wetlands in this watershed were rated as providing little value for wetland size and educational opportunities. This was because wetlands were very small on average (6.3 ± 5.1ha), and few were viewable from public roads, had parking for more than two vehicles, or had trail systems or boardwalks. No riverine wetlands were rated as being ecologically significant or locally rare, and none were classified as restored, established, or enhanced wetlands.

Non-tidal Depression Wetlands

Only 11 non-tidal depression sites (n=11) were assessed in the Brandywine watershed (Figure 16), far fewer than the target of 30 sites. This was because depressions turned out to be uncommon on the landscape when conducting assessments and field-verifying mapping classifications. Sample data were still extrapolated to the entire population of depression wetlands in the watershed, but caution should be exercised in this interpretation, keeping in mind the small sample size. Recall, too, that approximately one-third of depression assessment sites were in a heavily altered area adjacent to the Glenville wetland mitigation project (see 'Field Site Selection' in Methods).

Figure 16. A depression wetland in the Brandywine watershed.

Non-tidal depression wetlands in the Brandywine watershed all had mineral soils and most (81.8%) were in old growth forests (tree age > 50 years). They were characterized by common native species such as black willow (*Salix nigra*), poison ivy (*T. radicans*), green ash (*Fraxinus pennsylvanica*), silver maple (*Acer saccharinum*), button bush (*Cephalanthus occidentalis*), spicebush (*Lindera benzoin*), and red maple (*A. rubrum*). Depression wetlands had final DERAP scores that ranged from 48.0 to 78.0, with a mean score of 62.7 ± 8.6 (median=65.0) out of a maximum possible score of 82.0. The highest proportion of these wetlands was moderately stressed (72.7%), followed by severely stressed (18.2%) and minimally stressed (9.1%; Figure 17). Minimally stressed depressions were mostly affected by nutrient indicator species and development in the surrounding landscape. In addition to those stressors, moderately stressed depressions suffered from invasive species, weirs, dams, or roads in the wetlands, and roads in the surrounding landscape. Severely stressed depressions were strongly impacted by the same stressors minus weirs, dams, or roads (Table 14). Data for all sampled depression wetlands for all assessed metrics can be viewed in Appendix G.

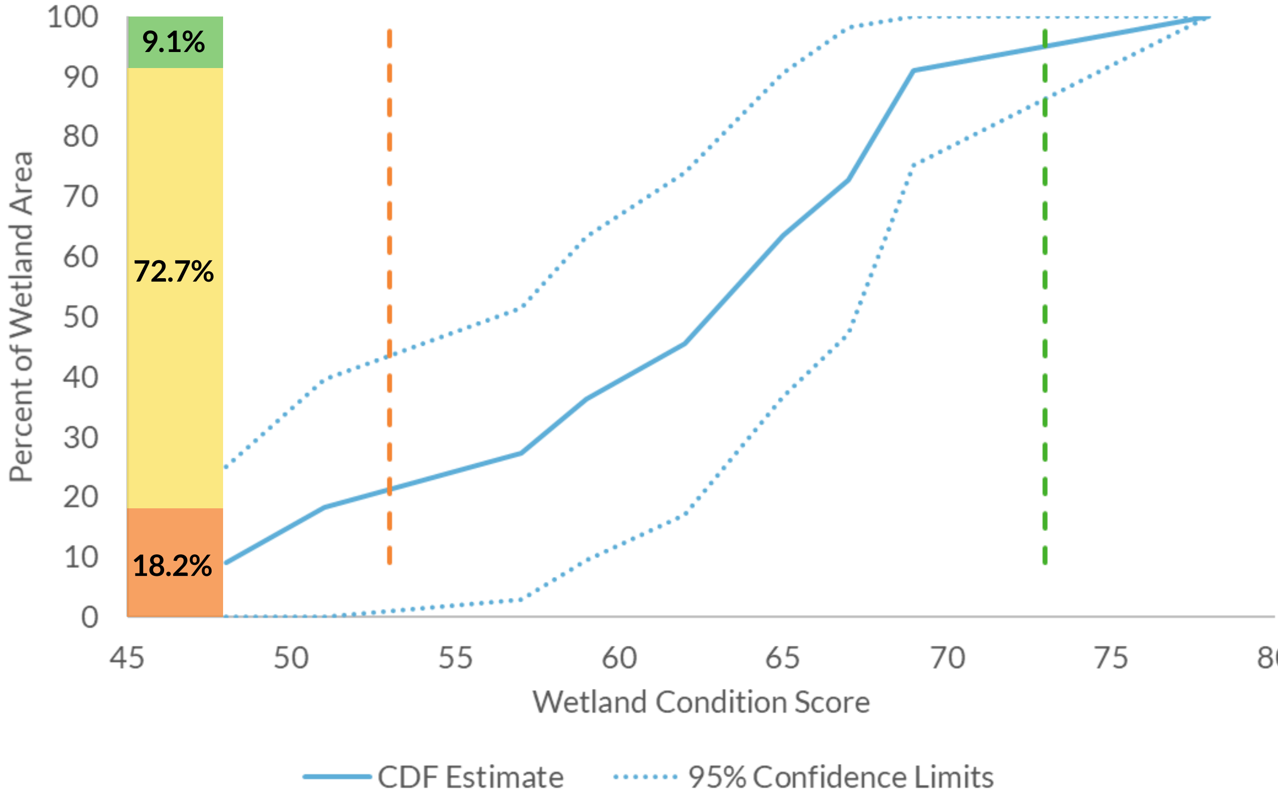


Figure 17. Cumulative distribution function (CDF) for non-tidal depression wetlands in the Brandywine watershed. The solid blue line is the population estimate and the dashed blue lines are 95% confidence intervals. Colored blocks on the y-axis show percent of wetlands within each condition category, where orange is severely stressed, yellow is moderately stressed, and green is minimally stressed. The orange and green dashed lines show breakpoints between condition categories.

Invasive species and nutrient indicator species were the most common habitat stressors in depressions, and both were found in 90.0% of wetlands (Table 14). Of depressions with invasive species, 60% had invasive plants covering 6-50% of wetland area, 30% had invasive plants covering >50% of wetland area, and 10% had invasive plants covering 1-5% of wetland area. Invasive plants that were found in depressions were multiflora rose (*R. multiflora*), European reed (*P. australis australis*), Japanese honeysuckle (*L. japonica*), purple loosestrife (*Lythrum salicaria*), autumn olive (*E. umbellata*), Japanese stiltgrass (*M. vimineum*), floating seedbox (*Ludwigia peploides*), reed canary grass (*P. arundinacea*) and stinging nettle (*U. dioica*). Of depressions with nutrient indicator species, 40% were dominated (>50%) by them and 60% were not dominated (<50%). Nutrient indicator species that were detected were black willow (*S. nigra*), European reed (*P. australis australis*), smooth rush (*Juncus effusus*), smartweeds (*Persicaria spp.*), spatterdock (*Nuphar advena*), flatsedges (*Cyperus spp.*), Japanese stiltgrass (*M. vimineum*), reed canary grass (*P. arundinacea*), seedboxes (*Ludwigia spp.*), and rice cutgrass (*L. oryzoides*). Pine plantations, forest harvesting, vegetation alterations, chemical defoliation, excessive herbivory, roads, and dense algal mats were absent from depressions.

Weirs, dams, or roads were common hydrology stressors and were found in 45.5% of depressions (Table 14). Wetlands with such stressors had water impounded on 10-75% of the wetland area. Ditching was somewhat common and was detected in 18.2% of depressions, with ditches ranging from slight to severe in depth and water conveyance. Fill was less common and was found in 9.1% of depressions. In all those cases, fill covered <10% of wetland area. No depressions contained stormwater inputs, point sources, excessive sedimentation, or microtopographic alterations.

Table 14. Listed are the most common stressors (>20% occurrence) in depression wetlands (see Table 8 for symbol category meanings). Also shown are the occurrence of stressors in each condition category (%min = % minimally stressed; %mod = % moderately stressed; %sev = % severely stressed).

Category	Stressor	% Total (n=11)	% Min (n=1)	% Mod (n=8)	% Sev (n=2)
	Invasive Species	90.9	0.0	100.0	100.0
	Nutrient indicator species	90.9	100.0	87.5	100.0
	Weir/dam/road	45.5	0.0	62.5	0.0
	Development in surrounding landscape	90.9	100.0	87.5	100.0
	Roads in surrounding landscape	36.4	0.0	25.0	100.0

Development and roads were the most common buffer stressors surrounding depression wetlands in this watershed (Table 14). Development surrounded 90.9% of depressions and was a mixture of commercial and industrial as well as residential development. Roads were found around 36.4% of wetlands, and all were two- or four-lane roads. Channelized streams or ditches around depressions were somewhat common, found surrounding 18.2% of wetlands. Less common buffer stressors included mowing (9.1%) and livestock or poultry operations (9.1%) in the surrounding landscape. Golf courses, landfill or waste disposal, recent forest harvesting, agriculture, and sand or gravel operations were not found immediately around depressions.

The highest proportion (63.6%) of depressions were rated as providing moderate value to people and wildlife in the watershed. Many were also rated as providing limited value (36.4%), while none were rated as providing rich value (Figure 18). Out of the attributes assessed, depressions offered the most value in terms of habitat structure and complexity. Common beneficial habitat features within wetlands were snags, large downed wood, coarse woody debris, water for amphibians, tree gaps, and tree and herbaceous cover. Depressions also provided some value to the local landscape through habitat availability. Buffer areas surrounding depressions were, on average, 76.7% ± 21.6% natural and unfragmented.

Additionally, depression wetlands also supplied some value through the DEN network, with many wetlands and their buffers entirely or partially within ecologically important corridors. Some flood storage and water quality values were supplied by depressions as well. This was because all depressions pooled water, many had wet water regimes (i.e., C or wetter in Cowardin classification), and many were rated as having moderate to high sediment retention capabilities. In contrast, depressions provided very little educational opportunities to the local community, as few were on public property with public access, and none were viewable from public roads, had parking for vehicles, or had trail or boardwalk systems. No depressions were considered locally rare or ecologically significant, and none were restored, established, or enhanced.

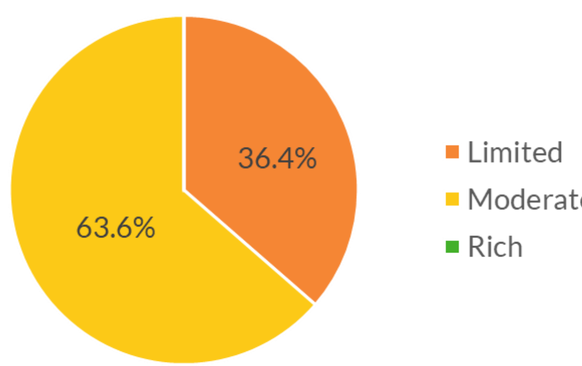


Figure 18. Proportion of depression wetlands in each value-added category.

Non-tidal Groundwater Seep Wetlands

Nineteen seep wetlands were assessed (n=19) in the Brandywine watershed, which represented a significantly lower sample size than the goal of 30 sites. This was largely because seeps were often mapped incorrectly, meaning either that they were entirely unmapped on state wetland maps (and therefore did not receive any random sample points) or polygons that were classified as seeps on maps were not actually seeps upon field verification. Sample data were still extrapolated to the entire watershed's population of this wetland type, though caution should be exercised in interpretation due to small sample size.

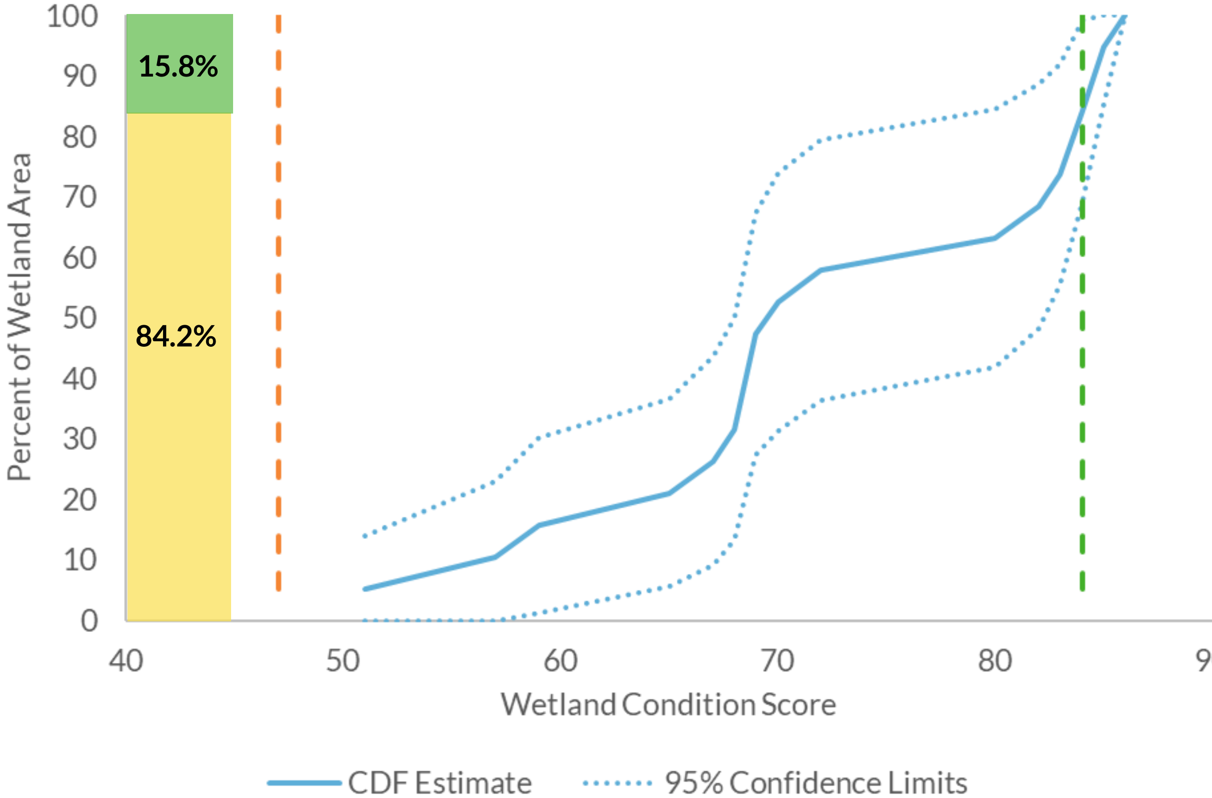


Figure 19. Cumulative distribution function (CDF) for non-tidal seep wetlands in the Brandywine watershed. The solid blue line is the population estimate and the dashed blue lines are 95% confidence intervals. Colored blocks on the y-axis show percent of wetlands within each condition category, where orange is severely stressed, yellow is moderately stressed, and green is minimally stressed. The orange and green dashed lines show breakpoints between condition categories.

On average, seeps scored 72.9 ± 10.7 (median 70.0) out of a maximum possible score of 91.0. Scores ranged from 51.0-86.0. Most seep wetlands were moderately stressed (84.2%), with the rest being minimally stressed (15.8%). No seeps were severely stressed in this watershed (Figure 19). Seeps were all natural and were classified as being either open canopy (36.8% of seeps; Figure 20) or closed canopy (63.2%; Figure 21). Common natives present in closed canopy seeps were skunk cabbage (*S. foetidus*), red maple (*A. rubrum*), jewelweed (*I. capensis*), cinnamon fern (*Osmundastrum cinnamomeum*), false nettle, (*B. cylindrica*), spicebush (*L. benzoin*), black gum (*N. sylvatica*), poison ivy (*T. radicans*), and jack in the pulpit (*Arisaema triphyllum*). In open canopy seeps, common native species included skunk cabbage (*S. foetidus*), sensitive fern (*Onoclea sensibilis*), smooth rush (*J. effusus*), black willow (*S. nigra*), smartweeds (*Persicaria spp.*), rice cutgrass (*L. oryzoides*), jewelweed (*I. capensis*), false nettle (*B. cylindrica*), and broadleaf arrowhead (*Sagittaria latifolia*). Minimally stressed seeps were affected by

Figure 20. An open canopy seep in the Brandywine watershed.

invasive species as well as development and roads in their buffers. In addition to those stressors, moderately stressed wetlands were impacted by weirs, dams, or roads and fill within wetlands, and by mowing in their buffers (Table 15).

Figure 21. A closed canopy seep in the Brandywine watershed.

Invasive species were the only common habitat stressors and were found in 100% of seep wetlands (Table 15). Multiflora rose (*R. multiflora*), Japanese stiltgrass (*M. vimineum*), European reed (*P. australis australis*), mile-a-minute (*P. perfoliata*), yellow iris (*Iris pseudacorus*), autumn olive (*E. umbellata*), Japanese honeysuckle (*L. japonica*), reed canary grass (*P. arundinacea*), English ivy (*H. helix*), European privet (*L. vulgare*), Japanese barberry (*B. thunbergii*), stinging nettle (*U. dioica*), and wineberry (*Rubus phoenicolasius*) were all invasive species present in seeps. Other habitat stressors were relatively uncommon. Roads were found in 10.5% of seeps, and 5.3% had other habitat stressors, such as natural gas pipelines. There were no pine plantations, chemical defoliation, excessive herbivory, vegetation alterations, clear or selective cutting, or dense algal mats in seep wetlands.

Fill and weirs, dams, or roads were the most prevalent hydrology stressors and were present in 21.1% of seeps (Table 15). Of the wetlands with fill, 25% of them had fill across less than 10% of the wetland area, and 75% of them had fill across 10-75% of the wetland area. Out of the seeps with weirs, dams, or roads within them, 50% had structures impounding water on less than 10% of the wetland surface, 25% had structures impounding water on 10-75% of the wetland area, and 25% had structures decreasing flooding in the wetland area. Stormwater inputs were slightly less common stressors and were found in 15.8% of seeps. Microtopographic alterations were even less common and were present in 10.5% of wetlands. There was no channelization, point sources, or excessive sedimentation in any seeps.

There were several widespread buffer stressors in landscapes surrounding seep wetlands, including development, roads, and mowing, which were found around 63.2%, 47.4%, and 31.6% of seeps, respectively (Table 15). Development ranged from commercial or industrial to residential, and roads were diverse in type, from dirt or gravel to two- or four-lane highways. Other buffer stressors were far less common. Channelized streams or ditches, agriculture, and golf courses were all present in landscapes surrounding 5.3% of seeps. There were no landfill or waste disposal areas, poultry or livestock operations, recent forest harvesting, or sand or gravel operations around seep wetlands in this watershed.

Most seep wetlands were rated as providing rich value to the local landscape (89.5%), with a smaller amount rated as moderate (10.5%) and none rated as limited (Figure 22). A significant driver of this pattern was

Table 15. Listed are the most common stressors (>20% occurrence) in seep wetlands (see Table 8 for symbol category meanings). Also shown are the occurrence of stressors in each condition category (%min = % minimally stressed; %mod = % moderately stressed; %sev = % severely stressed).

Category	Stressor	% Total (n=19)	% Min (n=3)	% Mod (n=16)	% Sev (n=0)
	Invasive Species	100.0	100.0	100.0	0.0
	Fill	21.1	0.0	25.0	0.0
	Weir/dam/road	21.1	0.0	25.0	0.0
	Development in surrounding landscape	63.2	33.3	68.8	0.0
	Roads in surrounding landscape	47.4	33.3	50.0	0.0
	Mowing in surrounding landscape	31.6	0.0	37.5	0.0

the fact that all seep wetlands were considered ecologically significant, meaning that they were important for specific plant and wildlife communities as Category One wetlands. In addition, seeps provided some value through the DEN ecological network because many wetlands and their buffers were either entirely or partially within ecologically important corridors. Seeps were also somewhat valuable in terms of habitat availability; on average, 72.1 ± 19.7% of land surrounding seep wetlands was natural and unfragmented. Seeps provided some value to the local landscape through habitat structure and complexity as well. Common habitat features in seeps that were important for wildlife included water for amphibians, tree and herbaceous cover, tree gaps, and coarse woody debris. These wetlands were also considered somewhat important for their flood storage and water quality capabilities, largely because they were all adjacent to surface waters and were all rated as having moderate to high sediment retention abilities.

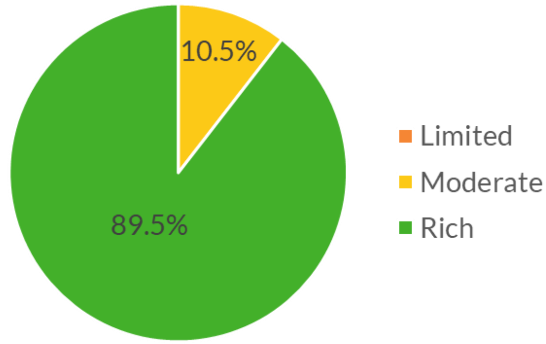


Figure 22. Proportion of seep wetlands in each value-added category.

Seep wetlands provided the least value to the local landscape in terms of education opportunities and wetland size. Although many seeps were on public property, few had parking for two or more vehicles or had trail or boardwalk systems. On average, seeps were very small in size at 4.7 ± 3.0ha.

Overall Condition and Watershed Comparison

Overall wetland condition in the Brandywine watershed was compared to 11 other watersheds that were previously assessed. To do this, condition proportions were combined (minimally, moderately, and severely

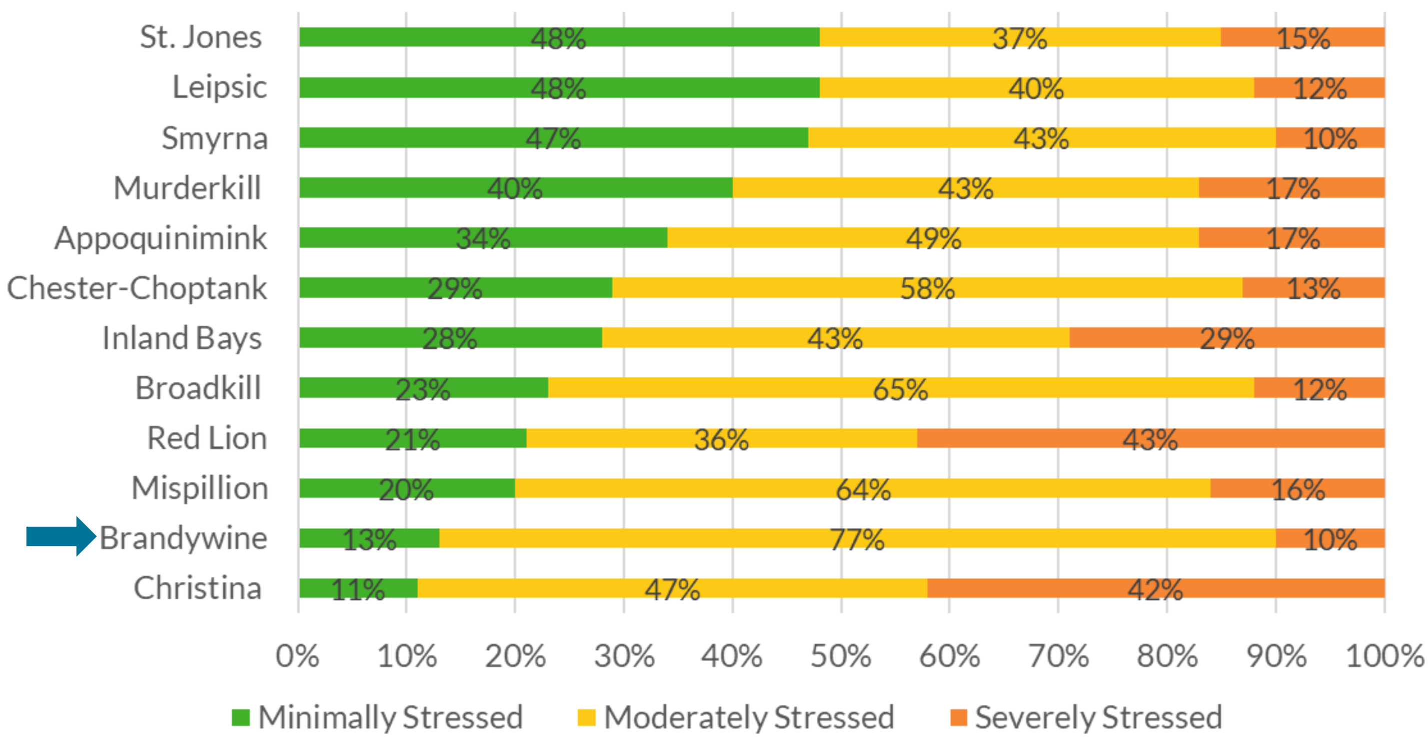


Figure 23. Comparison of overall condition categories for assessed watersheds throughout Delaware. Watersheds are listed in decreasing order of minimally stressed wetlands. Overall percentages shown are based on combined condition category percentages for all assessed wetland types that are weighted based on major wetland type acreage for each watershed.

stressed) for all major assessed wetland types and were weighted by the acreage of each type in each watershed.

Overall, the highest proportion of wetlands in the Brandywine watershed were moderately stressed (77%), followed by minimally stressed (13%) and severely stressed (10%). In terms of overall condition breakdown, the Brandywine watershed was most similar to the Mispillion watershed. Notably, it had the second lowest proportion of minimally stressed wetlands of all assessed watersheds, behind only the Christina watershed. The Brandywine watershed is adjacent to the Christina watershed, and the low proportions of minimally stressed wetlands in both areas are likely caused by the highly developed landscape of northern Delaware. However, the Brandywine watershed also tied the Smyrna watershed for having the lowest proportion of severely stressed wetlands (Figure 23).

Discussion

Acreage Trends

By 2017, the Brandywine watershed lost an estimated 26% of its historic wetland acreage since human settlement of the region, primarily because of urban and suburban development. Wetland losses that occurred in recent years between 1992 and 2017, which amounted to about 42 acres, were because of road or parking lot construction, urban or suburban development, or golf course creation. Most wetlands that were lost during this time period were riverine wetlands, depressions, or non-vegetated ponds. Because these wetlands were lost completely and converted to another land use, all functions that these wetlands performed were also lost entirely. These findings indicate that the lack of non-tidal wetland regulation in the state of Delaware, along with weak or inconsistent federal regulation and relaxed county requirements, have resulted in the continued destruction of non-tidal wetlands over time. These results aligned closely with trends seen statewide, as development was noted as being one of the leading causes for losses of vegetated non-tidal wetlands throughout all of Delaware from 1992 to 2007 (Tiner et al. 2011) and from 2007 to 2017 (DNREC 2022).

When things like housing developments or roads are constructed in wetland areas, they are prone to flooding, particularly if they are near streams or rivers. This endangers human lives and makes recovery efforts very expensive. Wetland restoration, if located where former wetlands existed and if constructed properly, can help recover some wetland acreage and function, but it is often very time consuming, expensive, and challenging. For instance, the community of Glenville was constructed in riverine wetlands, and the result was constant home and property flooding, causing danger to human lives and severe property destruction. It was a time consuming and expensive endeavor to relocate Glenville residents, demolish houses, and reconstruct wetlands. Better planning and stronger wetland protection could help avoid dangerous situations such as what occurred in Glenville, and wetlands could be preserved and allowed to perform their natural functions.

Increased regulation and enforcement in non-tidal wetlands at the federal, state, and county levels are necessary to prevent further acreage and function losses in the Brandywine watershed. Stricter regulations should prevent as much non-tidal wetland loss as possible. Regulations should encompass all non-tidal wetlands, regardless of size. Although some non-tidal wetlands tend to be small and geographically isolated, these types of wetlands often have specific characteristics, such as hydroperiod, that are crucial to the survival and reproduction of amphibians (Babbitt 2005), making them just as important to protect as larger wetlands. These geographically isolated wetlands are also important for base stream flow, groundwater recharge, and sediment retention, and can in some cases perform such functions better than other wetland types (Cohen et al. 2016).

It is possible, however, that some losses were permitted losses that were mitigated in some way. Where impacts are permitted, mitigation requirements should be strongly enforced, and significant effort should be made to replace wetland types and functions lost. Wetland mitigation can, if done properly, help offset some functional losses. For example, in this watershed, the Glenville wetland mitigation project was conducted in a place of need that also helped offset unavoidable wetland impacts elsewhere in the state. However, wetland mitigation and restoration projects in Delaware often do not resemble natural non-tidal wetlands and are frequently surrounded by unnatural berms (Haywood et al. 2020). In the case of Glenville, although the mitigation project was sited in a location where riverine wetlands historically existed, the wetland that was created does not resemble a natural riverine wetland and is surrounded by a large berm, preventing floodplain connection. That means that the mitigated wetlands are likely not functioning as the historic wetlands that were once there did.

It is essential to replace wetland types that have been destroyed and for restoration professionals to take care to mimic natural features and functions. The functionality of restored wetlands varies greatly depending on characteristics such as vegetation and hydrologic regime. Wetland restoration should continue, but care should be taken for restored wetlands to resemble natural wetland types and functions in the local landscape as closely as possible. This could help ensure that some of the wetland types and functions that have been lost are being replaced. However, it is difficult to mimic natural wetland characteristics in wetland restoration and it will take a long time or never reach natural conditions (Moreno-Mateos et al. 2012). It is therefore essential to not only continue to carefully restore wetlands and mitigate unavoidable impacts but to curb losses of natural wetlands in the first place.

Non-tidal wetland losses, together with the high proportion of private and unprotected wetlands in this watershed, underscore that more education and outreach is needed for private landowners. By understanding the benefits that wetlands provide, how to identify wetlands, and tips for caring for wetlands, landowners may be more willing to participate in voluntary conservation efforts. This idea is supported by results from a recent survey conducted in Delaware that showed that landowner perception of wetlands became more positive once landowners were presented with facts about wetlands (DNREC and OpinionWorks 2017).

Despite losses, the Brandywine watershed experienced a net gain in wetland acreage of about 121 acres between 1992 and 2017. However, a high proportion of gained wetland acreage (79%) was not natural, vegetated wetlands, but was instead non-vegetated ponds and pond edges. These ponds were usually created for residential or agriculture and livestock uses. These ponds usually had little to no natural buffer area around them, making them very vulnerable to indirect impacts such as polluted runoff and sedimentation. Most of these ponds were classified as unconsolidated bottom, areas of which have less than 30% aerial vegetative cover (FGDC 2013).

The Brandywine watershed also gained a small amount of non-tidal wetlands that were classified as flats, riverine wetlands, or depressions, though these only represented 21% of total gained acreage. Most of these gained wetlands had emergent vegetation, with far fewer having forest or scrub shrub vegetation. The fact that they were vegetated likely increased their chances of providing services such as nutrient transformation, retention of sediments and pollutants, conservation of biodiversity, climate mitigation, and provision of wildlife habitat (Tiner 2003). However, most of these wetlands were partially bordered or entirely surrounded by housing developments, roads, or agriculture. Such stressors can reduce wetland condition through polluted runoff or reduced wetland habitat connectivity (Faulkner 2004; Brand et al. 2010), thereby reducing the ability of those wetlands to perform beneficial functions fully.

When relating gains and losses, it is important to note that many losses were vegetated riverine, depression, or flat wetlands, yet the majority of wetlands gained were man-made, non-vegetated ponds. Forested wetlands are valuable for their water filtration capacity and ability to provide habitat. The functions being offered by open water ponds do not match those being lost by destruction of those natural wetlands. Non-vegetated agricultural or residential ponds can be beneficial to some generalist species by providing habitat where natural wetlands are scarce (Brand and Snodgrass 2009; Tiner et al. 2011). However, such wetlands most often do not provide the same functional value as natural wetlands, in part because they are largely non-vegetated, usually occur in a developed or agricultural landscape, and may be disconnected from groundwater because of liners. They may provide lower levels of certain functions, such as nutrient transformation, carbon sequestration, and sediment retention (Tiner 2003; Brand et al. 2010; Tiner et al. 2011).

Stormwater retention ponds have been shown to support fewer wetland-dependent plant and bird species compared with natural wetlands; this may in part be a result of their physical dissimilarities with natural wetlands, including steeper slopes and different and less variable hydroperiods (Rooney et al. 2015). Stormwater ponds may have different water chemistry, organic matter, and invertebrate communities compared with natural wetlands as well (Woodcock et al. 2010). Agricultural ponds may also provide wildlife habitat that is lower in quality than natural wetlands. For example, tadpoles may suffer reduced survival or growth rates in agricultural ponds because of polluted runoff from agricultural land (Peltzer et al. 2008). Thus, created ponds usually do not resemble natural wetlands and do not replace lost natural wetland functions. Non-tidal wetlands that changed from vegetated to non-vegetated likely experienced a similar relative decrease in ecosystem function. These findings further highlight the need for restoration and mitigation to focus on replacing wetland types and functions that have been lost. Where stormwater or agricultural ponds are constructed, it is important to have native vegetation within and surrounding the ponds to maximize functional capacity.

Non-tidal Wetland Condition and Value

Nearly half of all wetland types were privately owned in this watershed, which presents an opportunity for conservation. With so many wetlands on private property, state-level non-tidal wetland regulation and enforcement could prevent further wetland loss and degradation, particularly because non-tidal wetland condition was reduced largely by human impacts in this watershed. There is also a need for more education and outreach for private landowners. By understanding the benefits that wetlands provide and simple ways to conserve wetlands, landowners may be more willing to participate in conservation and restoration efforts voluntarily.

Buffer stressors were the most widespread types of stressors across all four assessed non-tidal wetland types in the Brandywine watershed. Development and roads were common in the landscapes surrounding wetlands of all four types. Mowing was also common surrounding flats, riverine wetlands, and seeps, and channelized streams or ditches were around many flat wetlands. Such unnatural land uses adjacent to non-tidal wetlands indicated that buffer zones around these wetlands were degraded. Buffers are natural areas adjacent to wetlands that can provide wildlife habitat and help shield wetlands from indirect impacts. Natural buffer areas surrounding wetlands can be just as important as wetlands, if not more so, to amphibians and reptiles, many of which require forested habitats adjacent to wetlands for foraging, overwintering, and habitat corridors for movement among wetlands (Semlitsch and Bodie 2003; Quesnelle et al. 2015; Finlayson et al. 2017).

Runoff polluted with chemicals and excess nutrients and sediment from development, roads, or mowed areas can enter wetlands directly if natural buffers do not separate wetlands from human activities. Stream channelization in buffers surrounding wetlands can affect wetland hydrology by influencing water flow into or away from the wetland. These data identify a need to conserve and improve buffers around non-tidal wetlands in the Brandywine watershed. Additionally, the prevalence of development near wetlands highlights the importance of utilizing BMPs. Such responsible practices, including things like limited mowing, vegetated riparian buffers, and reduced fertilizer usage, would dampen effects of indirect impacts by reducing harmful runoff of waste, excess nutrients, and chemicals (EPA 2005). BMPs such as these are listed in the Christina Basin PCS (Delaware Tributary Action Teams et al. 2011) as strategies to improve water quality and wetland health in and around the Red Clay Creek, White Clay Creek, Shellpot Creek, and Naamans Creek, which are all listed as impaired waters under Section 303(d) of the CWA. Agencies that work to improve wetland health and water quality should work together to evaluate wetland, stream, and water quality studies and look at issues and improvements as part of a whole-watershed framework. This would increase efficiency and effectiveness while reducing redundancy, hopefully leading to better wetland health and water quality alike.

Overall, non-tidal wetlands were in good or fair habitat condition except for the high prevalence of invasive plant species. Invasive plants were present in 100% of flat, riverine, and seep wetlands, and 91% of depressions. Invasive species can rapidly displace the native species that characterize high-functioning wetlands and that provide vital food and habitat for wildlife, thus decreasing wetland condition. It is also incredibly difficult to eradicate many invasive plant species once they are established. Therefore, invasive species should be removed or controlled as soon as possible both within and adjacent to non-tidal wetlands. This is particularly true in this watershed because invasive species were so widespread already and have high potential to spread and displace more native species. Environmental agencies should perform invasive species control and also conduct outreach to educate private landowners about removing invasive species and buying only native plants. In addition, most depressions (91%) had nutrient indicator species present, which are plant species that have been shown to flourish in depression wetlands containing excess nutrients. It is not surprising that so many depressions contained such species, because, as discussed above, runoff from development and roads surrounding wetlands can contain high amounts of nutrients and other pollutants.

Flat and riverine wetlands were in fair condition for hydrology, while depression and seep wetlands were in good hydrological condition. The most common hydrology stressors across all wetland types were fill and weirs, dams, or roads. Ditching was also widespread in flats. These types of stressors can degrade natural wetland hydrology by increasing, decreasing, or altering the flow of water through wetlands. When hydrology is disturbed, soil moisture and groundwater levels may be reduced (Faulkner 2004). Such disturbances have the potential to affect wetland plant communities, which are adapted to live in certain hydrologic conditions. Therefore, non-tidal wetland rehabilitation efforts in this watershed should target these hydrological issues to reestablish natural functions wherever possible. Additionally, stormwater inputs were somewhat common in riverine wetlands, which could introduce pollutants and trash into streams and wetlands. Increased state regulatory protections of non-tidal wetlands, and enforcement of those protections, would help ensure that hydrology impacts such as these do not occur in the first place.

A combination of wetland restoration and conservation is needed in the Brandywine watershed. The majority of all four wetland types were moderately stressed, meaning that natural wetlands of all types should be protected and conserved wherever possible before they experience more impacts and become severely stressed. If intact wetlands are maintained, communities will continue to benefit from the functions they provide, and money will not need to be spent on their restoration or the replacement of beneficial services in the future. However, since most were moderately stressed and not minimally stressed, wetlands have room for improvement and would benefit from restoration in this watershed. Restoration projects should pay special attention to common stressors that were detected in wetlands this watershed. For example, invasive species should be addressed through appropriate treatment measures to increase habitat condition and fill piles in wetlands should be removed to help promote natural hydrology. It is easier and cheaper to restore wetlands that are moderately stressed compared with those that are severely stressed or destroyed, so rehabilitation activities should be conducted as soon as possible to ensure that condition of non-tidal wetlands does not decline further. Continued monitoring of non-tidal wetlands is also important to detect changes in stressor and condition trends, which would help inform restoration efforts.

Highlighting the specific local values that non-tidal wetlands provided in this watershed, such as habitat availability and habitat structure and complexity, makes the case for increased protection of non-tidal wetlands even more compelling. Value-added data can also be used to inform wetland restoration and enhancement projects by focusing on improving value characteristics that were rated poorly in this watershed, such education potential, to heighten their value to the local landscape. Moreover, many moderately stressed non-tidal wetlands were still rated as providing moderate to rich value to the local landscape. This shows that in some ways even wetlands that have been negatively impacted by human activities can be valuable to local communities and wildlife, which strengthens the case for conservation and restoration of wetlands, even those in declining condition.

Finally, approximately 44% of sites that WMAP attempted to sample were not wetlands. This staggering number of dropped sites suggests that certain improvements were needed to the 2007 SWMP maps that were used to randomly select a sample population of vegetated, non-tidal wetlands in the Brandywine watershed (see 'Field Site Selection' in Methods). For example, mapped flats were often depicted as being on steep slopes and were found not to be wetlands in the field, showing the need for more careful referencing of elevation and topography data during the mapping process. This experience highlights the importance of having and using accurate wetland maps and updating them as much as possible. Updated, accurate maps allow for better landscape-level calculations and make field sampling much more efficient. As stated previously, the 2017 SWMP maps were used for many landscape-scale calculations in this report because the 2007 maps were found to be inconsistent in this watershed. State wetland maps in Delaware should continue to be updated on a regular basis, and areas that are known to be challenging for wetland mapping, such as the Brandywine watershed and the rest of the Piedmont region, should be given special care during the quality assurance process.

Management Recommendations

Based on field assessment data, landscape-level trend analyses, and thoughts presented in the Discussion section above, WMAP formed management recommendations for the Brandywine watershed. Recommendations are organized by audience: environmental scientists, researchers, and land managers; state, county, and local decision makers; and landowners. A summary of management recommendations and associated action items for the watershed can be found in Table 16.

Environmental Scientists, Researchers, and Land Managers

1. **Support vegetated buffers for non-tidal wetlands.** There is a strong need to establish, improve, and maintain adequate natural, vegetated buffers around non-tidal wetlands in this watershed. Such work would help minimize indirect impacts and ensure that wetlands can persist and function. Currently, New Castle County requires 50-foot buffers around non-tidal wetlands. Required buffer width around non-tidal wetlands should increase, and all buffer regulations should be more strongly and regularly enforced. Funding should be secured and leveraged for improving buffers on currently protected lands, and for acquiring buffer land to extend riparian habitat corridors and connect more habitat hotspots. Vegetated buffers should be established and maintained around created ponds as well to improve their functional potential and health.

2. **Continue to increase citizen education and involvement through effective outreach.** Over half of all non-tidal, vegetated wetlands in the Brandywine watershed were on unprotected lands, and wetland loss and degradation were largely caused by human impacts. By increasing wetland education to landowners and informing them about the benefits wetlands can provide, landowners may be more willing to take part in voluntary stewardship activities that can benefit wetlands around them, thereby decreasing wetland loss and degradation. To accomplish effective public outreach, it is essential to identify the audience, create an active dialogue with landowners, to encourage active, hands-on participation in discussions and activities, and to create an understanding of how wetlands are relevant to the public (Calhoun et al. 2014, Varner 2014). For example, in order to address the goal of increased landowner wetland stewardship, DNREC's WMAP created a website called the Freshwater Wetland Toolbox in 2017 that allows landowners to look up their property and locate wetlands, highlighting ways to care for backyard wetlands (see link on pg. 54). More outreach tools and programs should be created to address other specific public education goals. Such tools and programs should constantly be evaluated to gauge their effectiveness in addressing goals and to improve outreach efforts (Varner 2014).

3. **Perform wetland monitoring, conservation, and restoration activities.** It is essential to continue to monitor wetland condition over time to detect common stressors and trends and address them as quickly as possible. Recent wetland monitoring indicated that most wetlands were moderately stressed in this watershed, meaning that rehabilitation can increase the overall health of these existing wetlands. Protection and preservation of wetlands can help maintain natural wetland acreage in this watershed as well, and restoration of former wetlands could help recover some of the watershed's lost wetland acreage. When possible, environmental organizations can work to preserve or restore wetlands that are not currently protected through land acquisition or conservation easement. This would help curb wetland acreage losses in this watershed while also protecting their health. Projects should account for watershed-specific conditions. For example, the overall intact habitat features of non-tidal wetlands, aside from invasive species, should be kept in place, while the buffer stressors of all wetland types should be addressed. Value added results can also strengthen cases for wetland conservation and restoration and inform wetland enhancement and rehabilitation goals. For instance, the fact that all non-tidal wetland types provided significant value in terms of habitat structure and complexity in this watershed could fortify arguments for wetland conservation. Care should be taken when restoring wetlands to have them

resemble natural, vegetated wetlands as closely as possible. Professionals can use landscape-level screening tools such as the Delaware Watershed Resources Registry (WRR) to help locate highly suitable areas for wetland restoration and preservation (WRR 2021).

4. **Control the extent and spread of non-native invasive plant species.** All assessed wetland classes in the Brandywine watershed were negatively affected by invasive species. To improve wetland health, the extent and spread of non-native invasive plant species needs to be controlled. DNREC has a Phragmites Control Program to help combat the spread of the invasive European reed. This program has the potential to continue to help improve wetland health on public land and private holdings that have between five and 200 acres of *P. australis australis* (DNREC n.d.-b). However, many other invasive species besides the European reed were prevalent in wetlands in this watershed, such as Japanese honeysuckle, multiflora rose, Japanese stiltgrass, and reed canary grass. There is currently no program in place to control these invasive species. It would therefore be beneficial to expand invasive plant species control efforts to include more species besides just the European reed. Education and awareness, such as efforts made by the Delaware Invasive Species Council (DISC 2022), are important components of this by informing landowners about how to identify and remove undesirables and only plant native species.

5. **Improve coordination of watershed-based efforts both within and among agencies and municipalities.** It has been demonstrated from thorough data collection that non-tidal wetlands, as well as many waterbodies, within the Brandywine watershed are degraded from direct and indirect human impacts. To best improve water quality, and wetland health and function in this watershed, state and local environmental agencies and municipalities should better coordinate efforts. Water resources should not be assessed and reported independently of one another but should rather be viewed as parts of the whole watershed. Improved coordination could help maximize funding opportunities, reduce any redundancy of data collection efforts, and make clearer management recommendations.

6. **Continue to regularly update state wetland maps in Delaware.** Wetland maps in Delaware have historically been updated every 10 to 15 years. At the time of random wetland point selection for the Brandywine watershed, the 2007 SWMP maps were the most recent available. Nearly half of sites (44%) that WMAP attempted to sample were not wetlands and had to be dropped from sampling because of errors in the 2007 maps. Mapped wetlands, particularly flats, were often found to be on steep slopes and were found not to be wetlands in the field. When the newest 2017 SWMP maps were being reviewed for quality assurance, the Brandywine watershed was an area of special focus because of the known 2007 mapping issues in the watershed. The 2017 SWMP maps were therefore more accurate than the 2007 SWMP maps for the Brandywine watershed. Because of cases like this, state wetland maps in Delaware should continue to be updated on a regular basis, and areas that are known to be challenging for wetland mapping, such as the Brandywine watershed and the rest of the Piedmont region, should be given special care during the quality assurance process.

Decision Makers (State, County, and Local)

1. **Improve regulatory protection of non-tidal wetlands through state, county, and local programs.** Without increased regulatory protection, loss of non-tidal wetlands in the Brandywine watershed will probably continue, especially because most losses in this watershed were because of direct human impacts (i.e. development, roads, golf courses). Acreage losses will translate into loss of ecosystem services and values. Degradation of non-tidal wetlands from anthropogenic stressors, such as those commonly found in the Brandywine watershed (e.g., weirs, dams, or roads, fill) will likely also continue without increased protection. In addition, over half (52%) of all non-tidal wetland types were located on unprotected land, leaving them vulnerable to impacts. These facts highlight the need for improved protection to fill the gaps left by uncertainty in the definitions of the WOTUS and to address the lack of state regulation. Conservation of non-tidal wetlands will likely be most effective if state regulation is combined with smaller-scale efforts from counties, local governments and organizations, stakeholders,

and landowners. Such collaborative efforts can make everyone feel involved and informed, while successful solutions can be reached that simultaneously conserve wetlands and integrate interests of many parties (Calhoun et al. 2014, 2017). A state regulatory program in concert with county and local programs would reduce the ambiguity surrounding non-tidal wetland regulation and provide a comprehensive and clear means to protect these wetlands in the entire state. Regulations should aim to protect non-tidal wetlands of all sizes, including small wetlands like seeps, and should also include geographically isolated wetlands. Local regulations can be incorporated into municipal and/or county code and homeowner associations to protect wetland areas of special significance. In addition, the development of incentive programs could attract landowner interest in conserving wetlands and the beneficial ecosystem services that they provide. Where impacts are permitted, mitigation requirements should be strongly enforced, and effort should be made to replace natural wetland types and functions lost.

2. **Develop incentives and legislation to establish, maintain, and improve natural wetland buffers.** The data presented in this report demonstrate a clear need for establishment, improvement, and maintenance of natural buffers around non-tidal wetlands. To further improve wetland condition, buffers need to be kept as wide and undisturbed as possible, and development, roads, and mowing within buffer areas needs to be prevented. Currently, New Castle County requires 50-foot buffers around non-tidal wetlands. Required buffer width around non-tidal wetlands should increase, and all buffer regulations should be more strongly and regularly enforced. Incentive programs could also attract landowner interest in maintaining natural buffers between non-tidal wetlands and human activity to reduce negative indirect impacts to wetlands and provide crucial wildlife habitat. Development of incentives or legislation, or improvements to any existing local legislation, for buffer setbacks would help to prevent further buffer degradation or destruction. Additionally, municipalities and developers should be required to use BMPs to reduce indirect impacts to wetlands from non-point source pollution. Aside from maintaining natural buffers, BMPs could include preserving open space in urban areas, using permeable paving materials, rebuilding in areas that were previously constructed, and enacting slope restrictions for building to discourage erosion (EPA 2005).

3. **Secure funding for wetland rehabilitation, restoration, and preservation.** Overall, 77% of wetlands were moderately stressed and 10% of wetlands were severely stressed in the Brandywine watershed, suggesting that rehabilitation can make a large impact on improving wetland health in this watershed. This means that efforts should focus on restoring features and functions within existing wetlands. It is important to prioritize wetland preservation as well. Preservation of wetlands that are already healthy (i.e., the 13% of wetlands that were minimally stressed) will ensure that they continue to provide beneficial ecosystem services in the future, while preservation of less healthy wetlands can reduce the likelihood of further degradation and increase the likelihood that rehabilitation actions will occur. Funding should be secured to continue and expand programs that already exist in Delaware that can help conserve wetlands, including the Delaware Open Space Program (DNREC n.d.-c) and the Delaware Forestland Preservation Program (DE DDA n.d.). New funding opportunities should also be explored. If former wetlands are restored or new ones created, care should be taken to replace the same type of wetland lost and to replicate natural features and processes as much as possible. Projects should ideally be installed in wet areas with hydric soils. Note that stormwater, agriculture, and golf course ponds are not functional substitutes for natural, vegetated wetlands.

Landowners

1. **Protect and maintain the buffers around wetlands.** Buffers are natural, vegetated areas adjacent to wetlands that can help wetlands stay in good condition. Wetland buffers trap sediments and excess nutrients and filter pollutants before they reach wetlands. Buffers also slow stormwater runoff from nearby impervious surfaces, such as roads. In this way, buffers can protect wetlands from some of the

negative indirect impacts associated with roads, development, and agriculture that prevent wetlands from functioning at their fullest capacity. Buffers are also vital for the survival of wetland wildlife, including many species of reptiles and amphibians. In the Brandywine watershed, wetland buffers were degraded, due mostly to development, roads, and mowing. When buffers are degraded in this way, they do not perform ecosystem services to the same degree as when buffers are undisturbed. To maintain natural wetland buffers, avoid human activities (e.g., stream channelization, ditching, agriculture, or mowing) adjacent to and within existing buffers, and avoid cutting down any vegetation along streams and wetlands. Buffers can also be improved by planting native plant species between open spaces and waterways.

2. **Preserve or restore wetlands that are on private property.** Nearly half of the wetlands in the Brandywine watershed were located on privately-owned land, and a little less than half of vegetated wetlands were on protected land. This means that landowners play an important role in maintaining wetland acreage and function through wetland protection and stewardship. There are many ways that landowners can engage with the natural wetlands right in their backyards whether they have a small property or own a large area. For large landholdings, one of the best ways to do so is to protect or restore wetlands through conservation easements, which can be accomplished through programs such as the Agricultural Conservation Easement Program (ACEP; NRCS n.d.-a) or the Delaware Forestland Preservation Program (DE DDA n.d.). Easements can protect wetlands in their natural state from future development for a number of years or permanently while providing financial incentives. For smaller property owners, planting native species and removing invasive species are two other important actions, especially because invasive species were common in all non-tidal wetland types in this watershed. They can also avoid mowing grasses and picking up downed logs and branches within wetlands because those features provide important habitat for wildlife. In addition, leaving the hydrology intact by allowing waterways to flow naturally without being dug out, straightened, or impounded, by not adding ditches to drain wet areas, and by not adding fill to any part of wetlands, will help ensure that wetlands will remain healthy and fully functioning. WMAP's Freshwater Wetland Toolbox website allows landowners to see if wetlands exist on their property and to discover more ways in which they can benefit wetlands on their land (see link on pg. 54).

3. **Utilize BMPs in urban and suburban settings.** In this watershed, development, roads, and mowing were found near many non-tidal wetlands, suggesting that indirect effects on wetlands were occurring from surrounding land use. BMPs can be used in urban and suburban settings to limit effects of non-point source pollution. These include practices such as washing cars on grass, properly disposing of pet waste and chemicals, minimizing use of fertilizers and pesticides on lawns, installing rain barrels or gardens, and installing pervious pavement at home (EPA 2005). Another beneficial BMP is reducing mowed lawn areas by instead planting wildflowers, which provide habitat for birds and pollinators and reduce stormwater runoff. DNREC's Non-Point Source Program provides some funding opportunities to help landowners and other public or private entities reduce non-point source pollution, such as the Section 319 grant (DNREC n.d.-d). Funding for BMPs is also available through several programs administered by the Natural Resources Conservation Service (NRCS n.d.-b). Delaware's Livable Lawns program is another great resource for landowners, as it provides information about how to make lawncare more friendly to waterways (Delaware Livable Lawns 2020).

Table 16. Summary of management recommendations and associated action items for different audiences.

	Recommendation	Action Summary
Environmental Scientists, Researchers, and Land Managers	Support vegetated buffers for non-tidal wetlands.	1. Secure funding for improving and protecting buffers.
	Continue to increase citizen education and involvement through effective outreach.	1. Create outreach materials tailored to specific audiences.
		2. Encourage hands-on public participation in wetland stewardship activities.
	Perform wetland monitoring, conservation, and restoration activities.	1. Continue to monitor wetland condition and stressors to guide restoration efforts.
		2. Preserve or restore wetlands through land acquisitions or conservation easements.
	Control the extent and spread of non-native invasive plant species.	1. Continue to control *P. australis* through the DNREC's Phragmites Control Program.
		2. Expand invasive plant control efforts to species other than just *P. australis* .
		3. Educate landowners about how to identify and remove invasive species and plant native species.
	Improve coordination of watershed-based efforts both within and among agencies and municipalities.	1. Evaluate results from wetland, stream, and water quality studies with a whole-watershed framework.
	Continue to regularly update state wetland maps in Delaware.	1. Continue to regularly update state wetland maps, giving special attention to challenging areas during the quality assurance process.
Decision Makers (State, County, Local)	Improve regulatory protection of non-tidal wetlands through state, county, and local programs.	1. Create a state regulatory program for non-tidal wetlands that includes small and geographically isolated wetlands.
		2. Create incentives to encourage landowners to protect wetlands on their property.
		3. Enforce mitigation requirements where wetland impacts are unavoidable.
	Develop incentives and legislation to establish, maintain, and improve natural wetland buffers.	1. Increase buffer width to at least 75ft around non-tidal wetlands and regularly enforce regulations.
		2. Create incentives to encourage landowners to protect wetland buffers on their property.
		3. Encourage the use of BMPs in urban and suburban areas to reduce nonpoint source pollution to nearby wetlands.
	Secure funding for wetland rehabilitation and preservation.	1. Support and expand programs in Delaware that conserve wetlands.
Landowners	Protect and maintain the buffers around wetlands.	1. Plant native plants in buffer areas along wetlands and waterways.
		2. Avoid activities like mowing, development, grazing, etc. in buffer areas along wetlands and waterways.
	Preserve or restore wetlands that are on private property.	1. Protect wetlands in their natural states through conservation easements.
		2. Remove invasive plants and plant only native species.
		3. Avoid ditching and draining, impounding water, and placing fill in wetlands.
	Utilize best management practices (BMPs) in agricultural operations and in suburban settings.	1. Use BMPs in urban and suburban areas to reduce nonpoint source pollution and indirect impacts to wetlands.

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Acronyms

All acronyms used in this report are defined in the table below. Acronyms are listed in alphabetical order.

Acronym	Definition
AA	Assessment Area
ACEP	Agricultural Conservation Easement Program
AIC	Akaike's Information Criteria
BMP	Best Management Practice
CDF	Cumulative Distribution Function
CWA	Clean Water Act
DECAP	Delaware Comprehensive Assessment Procedure
DelDOT	Delaware Department of Transportation
DEN	Delaware Ecological Network
DERAP	Delaware Rapid Assessment Procedure
DNREC	Department of Natural Resources and Environmental Control
EMAP	Ecological Monitoring and Assessment Program
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
GIS	Geographic Information Systems
GPS	Global Positioning System
HGM	Hydrogeomorphic
HUC	Hydrologic Unit Code
IWC	Index of Wetland Condition
LLWW	Landscape Position, Landform Type, Waterbody Type, Waterflow Path
LULC	Land Use and Land Cover
NPS	National Park Service
NRCS	Natural Resources Conservation Service
NVF	National Vulcanized Fiber
NWI	National Wetland Inventory
PCS	Pollution Control Strategy
QDR	Qualitative Disturbance Rating
SGCN	Species of Greatest Conservation Need
SWMP	Statewide Wetland Mapping Project
TMDL	Total Maximum Daily Load
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USFWS	United States Fish and Wildlife Service
WMAP	Wetland Monitoring and Assessment Program
WOTUS	Waters of the United States
WRR	Watershed Resource Registry

Appendix A: Qualitative Disturbance Rating (QDR) Category Descriptions

Qualitative Disturbance Rating: Assessors determine the level of disturbance in a wetland through observation of stressors and alterations to the vegetation, soils, and hydrology in the wetland site, and the land use surrounding the site. Assessors should use best professional judgment (BPJ) to assign the site a numerical Qualitative Disturbance Rating (QDR) from least disturbed (one) to highly disturbed (six) based on the narrative criteria below. General description of the minimal disturbance, moderate disturbance, and high disturbance categories are provided below:

A) **Minimal Disturbance Category (QDR one or two):** Natural structure and biotic community maintained with only minimal alterations. Minimal disturbance sites have a characteristic native vegetative community, unmodified water flow into and out of the site, undisturbed microtopographic relief, and are in a landscape of natural vegetation (100 or 250m buffer). Examples of minimal alterations include a small ditch that is not conveying water, low occurrence of invasive species, individual tree harvesting, and small areas of altered habitat in the surrounding landscape, which does not include hardened surfaces along the wetland/upland interface. Use BPJ to assign a QDR of one or two.

B) **Moderate Disturbance Category (QDR three or four):** Moderate changes in structure and/or the biotic community. Moderate disturbance sites maintain some components of minimal disturbance sites such as unaltered hydrology, undisturbed soils and microtopography, intact landscape, or characteristic native biotic community despite some structural or biotic alterations. Alterations in moderate disturbance sites may include one or two of the following: a large ditch or a dam either increasing or decreasing flooding, mowing, grazing, moderate stream channelization, moderate presence of invasive plants, forest harvesting, high impact land uses in the buffer, and hardened surfaces along the wetland/upland interface for less than half of the site. Use BPJ to assign a QDR of three or four.

C) **High Disturbance Category (QDR five or six):** Severe changes in structure and/or the biotic community. High disturbance sites have severely disturbed vegetative community, hydrology, and/or soils as a result of ≥ 1 severe alterations or > 2 moderate alterations. These disturbances lead to a decline in the wetland's ability to effectively function in the landscape. Examples of severe alterations include extensive ditching or stream channelization, recent clear cutting or conversion to an invasive vegetative community, hardened surfaces along the wetland/upland interfaces for most of the site, and roads, excessive fill, excavation or farming in the wetland. Use BPJ to assign a QDR of five or six.

Appendix B: DERAP Stressor Codes and Definitions

Habitat Category (within 40m radius of sample point)	
Hfor50	Forest age 31-50 years
Hfor30	Forest age 16-30 years
Hfor15	Forest age 3-15 years
Hfor2	Forest age ≤2 years
Hcc10	<10% of AA clear cut within 50 years
Hcc50	11-50% of AA clear cut within 50 years
Hcc100	>50% of AA clear cut within 50 years
Hforsc	Selective cutting forestry
Hpine	Forest managed or converted to pine
Hchem	Forest chemical defoliation
Hmow	Mowing in AA
Hfarm	Farming activity in AA
Hgraz	Grazing in AA
Hnorecov	Cleared land not recovering
Hinv1	Invasive plants cover <1% of AA
Hinv5	Invasive plants cover 1-5% of AA
Hinv50	Invasive plants cover 6-50% of AA
Hinv100	Invasive plants cover >50% of AA
Hherb	Excessive Herbivory/Pinebark Beetle/Gypsy Moth
Halgae	Nutrients dense algal mats
Hnis50	Nutrient indicator plant species cover <50% of AA
Hnis100	Nutrient indicator plant species cover >50% of AA
Htrail	Non-elevated road
Hroad	Dirt or gravel elevated road in AA
Hpave	Paved road in AA
Hydrology Category (within 40m radius of sample point)	
Wditchs	Slight Ditching; 1-3 shallow ditches (<0.3m deep) in AA
Wditchm	Moderate Ditching; 3 shallow ditches in AA or 1 ditch >0.3m within 25m of edge of AA
Wditchx	Severe Ditching; >1 ditch 0.3-0.6 m deep or 1 ditch > 0.6m deep within AA
Wchannm	Channelized stream not maintained
Wchan1	Spoil bank on one or both sides of stream
Wchan2	Spoil bank on same side of stream as AA
Wincision	Natural stream channel incision
Wdamdec	Weir/Dam/Road decreasing site flooding
Wimp10	Weir/Dam/Road impounding water on <10% of AA
Wimp75	Weir/Dam/Road impounding water on 10-75% of AA
Wimp100	Weir/Dam/Road impounding water on >75% of AA
Wstorm	Stormwater inputs
Wpoint	Point source (non-stormwater)
Wsed	Excessive sedimentation on wetland surface

Hydrology Category (continued)	
Wfill10	Filling or excavation on <10% of AA
Wfill75	Filling or excavation on 10-75% of AA
Wfill100	Filling or excavation on >75% of AA
Wmic10	Microtopographic alterations on <10% of AA
Wmic75	Microtopographic alterations on 10-75% of AA
Wmic100	Microtopographic alterations on >75% of AA
Wsubsid	Soil subsidence or root exposure
Landscape/Buffer Category (within 100m radius outside site/AA)	
Ldevcom	Commercial or industrial development
Ldevres3	Residential development of >2 houses/acre
Ldevres2	Residential development of 1-2 houses/acre
Ldevres1	Residential development of <1 house/acre
Lrdgrav	Dirt or gravel road
Lrd2pav	2-lane paved road
Lrd4pav	≥4-lane paved road
Llndfil	Landfill or waste disposal
Lchan	Channelized streams or ditches >0.6m deep
Lag	Row crops, nursery plants, or orchards
Lagpoul	Poultry or livestock operation
Lfor	Forest harvesting within past 15 Years
Lgolf	Golf course
Lmow	Mowed area
Lmine	Sand or gravel mining operation

Appendix C: DERAP IWC Stressors and Weights

Category/Stressor Name*	Code	Stressor Weights**		
*DERAP stressors excluded from this table are not in the rapid IWC calculation.		Flats	Riverine	Depression
Habitat Category (within 40m radius site)				
Mowing in AA	Hmow	15	3	24
Farming activity in AA	Hfarm			
Grazing in AA	Hgraz			
Cleared land not recovering in AA	Hnorecov			
Forest age 16-30 years	Hfor16	5	4	2
≤10% of AA clear cut within 50 years	Hcc10			
Forest age 3-15 years	Hfor3	19	7	12
Forest age ≤2 years	Hfor2			
11-50% of AA clear cut within 50 years	Hcc50			
>50% of AA clear cut within 50 years	Hcc100			
Excessive Herbivory	Hherb	4	2	2
Invasive plants dominating	Hinvdom	2	20	7
Invasive plants not dominating	Hinvless	0	5	7
Chemical Defoliation	Hchem	5	9	1
Managed or Converted to Pine	Hpine			
Non-elevated road in AA	Htrail	2	2	2
Dirt or gravel elevated road in AA	Hroad			
Paved road in AA	Hpave			
Nutrient indicator species dominating AA	Hnutapp	10	12	10
Nutrients dense algal mats	Halgae			
Hydrology Category (within 40m radius site)				
Slight Ditching	Wditchs	10	0	5
Moderate Ditching	Wditchm		0	
Severe Ditching	Wditchx	17	0	
Channelized stream not maintained	Wchannm	0	13	0
Spoil bank on one or both sides of stream	Wchan1	0	31	0
Spoil bank on same side of stream as AA	Wchan2	0		0
Stream channel incision	Wincision	0	21	0
WeirDamRoad decreasing site flooding	Wdamdec	2	2	2
WeirDamRoad/Impounding <10%	Wimp10			
WeirDamRoad/Impounding 10-75%	Wimp75			
WeirDamRoad/Impounding >75%	Wimp100			
Stormwater Inputs	Wstorm	2	2	2
Point Source (non-stormwater)	Wpoint			
Excessive Sedimentation	Wsed			

Appendix C: DERAP IWC Stressors and Weights

Hydrology Category (continued)	Code	Flats	Riverine	Depression
Filling, excavation on <10% of AA	Wfill10	2	0	8
Filling, excavation on 10-75% of AA	Wfill75	16	11	2
Filling, excavation on >75% of AA	Wfill100			
Soil Subsidence/Root Exposure	Wsubsid	7	0	0
Microtopo alterations on <10% of AA	Wmic10			
Microtopo alteations on 10-75% of AA	Wmic75	16	11	2
Microtopo alterations on >75% of AA	Wmic100			
Buffer Category (100m radius around site)				
Development- commercial or industrial	Ldevcom	1 buffer stressor = 3	1 buffer stressor = 1	1 buffer stressor = 4
Residential >2 houses/acre	Ldevres3			
Residential ≤2 houses/acre	Ldevres2			
Residential <1 house/acre	Ldevres1			
Roads (buffer) mostly dirt or gravel	Lrdgrav	2 buffer stressors = 6	2 buffer stressors = 2	2 buffer stressors = 8
Roads (buffer) mostly 2- lane paved	Lrd2pav			
Roads (buffer) mostly 4-lane paved	Lrd4pav			
Landfill/Waste Disposal	Llndfil			
Channelized Streams/ditches >0.6m deep	Lchan			
Row crops, nursery plants, orchards	Lag			
Poultry or Livestock operation	Lagpoul			
Forest Harvesting Within Last 15 Years	Lfor	≥ 3 buffer stressors = 9	≥ 3 buffer stressors = 3	≥ 3 buffer stressors = 12
Golf Course	Lgolf			
Mowed Area	Lmow			
Sand/Gravel Operation	Lmine			
Intercept/Base Value		95	91	82
Flats IWCrapid= 95 -(∑weights(Habitat+Hydro+Buffer))				
Riverine IWCrapid= 91 -(∑weights(Habitat+Hydro+Buffer))				
Depression IWCrapid= 82 -(∑weights(Habitat+Hydro+Buffer))				

**Stressors with weights in boxes were combined during calibration analysis and are counted only once, even if more than one stressor is present.

Appendix D: Report Card Grading Scales

The following is the letter grade scale used in wetland health report cards for overall watershed grades, overall wetland type grades, and habitat and hydrology grades within wetland types (left), and the letter grade scale used for buffer grades within wetland types (right):

Score Range	Letter Grade
97-100	A+
93-96	A
90-92	A-
87-89	B+
83-86	B
80-82	B-
77-79	C+
73-76	C
70-72	C-
67-69	D+
63-66	D
60-62	D-
0-59	F

Average Stressor Tally Range	Letter Grade
0-0.60	A
0.61-1.2	B
1.21-1.8	C
1.81-2.4	D
2.41-3.0	F

Once letter grades are determined, wetland types as well as their attribute categories (habitat, hydrology, and buffer) are color-coded and placed on a qualitative wetland health scale shown below. This color-coded wetland health scale is designed to make public interpretation of wetland health as clear as possible.

Letter Grade	Wetland Health Scale	Color
A	Excellent	
B	Good	
C	Fair	
D	Poor	
E	Very Poor	

Appendices E-H, as well as the Brandywine report card, are stored as a separate files and can be found online within the Delaware Wetlands Library of Wetland Health Reports.

This report and other watershed condition reports, assessment methods, scoring protocols, and wetland health report cards can be found on the Wetland Monitoring and Assessment Program's website:

https://dnrec.alpha.delaware.gov/watershed-stewardship/wetlands/

Data collected for this report are publicly available for viewing and downloading for non-tidal wetlands.

Other helpful resources described in this report include the Freshwater Wetland Toolbox and the Delaware Watershed Resources Registry.